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Simulation of city evacuation coupled to flood dynamics

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Accompanying booklet

abstracts of all presentations and posters



6th International Conference on Pedestrian and Evacuation Dynamics - PED 2012

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

IVT Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

Opening

Wednesday, 6 June - 08.45

Ulrich Weidmann, Eidgenössische Technische Hochschule ETH, Zürich SWITZERLAND

Wednesday, 6 June - 09.00

Urs Walter, Fachstelle Fussgänger- und Radverkehr Stadt Zürich, Zürich SWITZERLAND

Keynote

Wednesday, 6 June - 09.30

Peter Jenkins, Building Design Partnership, Manchester UNITED KINGDOM

Shaping the space: turning function into inspiration

It is impossible to extract from the station design process the importance of pedestrian flow management. Many aspects of the development of concepts influence (and are influenced by) the movement and activities of passengers:

- Making space for diverse activities
- Relative needs and behaviour of different users
- Designing for speed of movement
- Heritage constraints
- Working with the pedflow analysis
- Natural & guided wayfinding
- The gateway role of a station
- The station as a destination in its own right
- Permeability
- Safety & security

The presentation will cover these and other themes, providing an explanation of the importance of gaining an understanding of pedestrian behaviour to our work.

Oral presentations

Wednesday, 6 June - 10.00

- A.1 *Tobias Kretz, PTV Planung Transport Verkehr AG, Karlsruhe GERMANY*
The effect of integrating travel time
- A.2 *Verena Reuter, Technische Universität Kaiserslautern, Kaiserslautern GERMANY*
On modeling groups in crowds: empirical evidence and simulation results including large groups
- A.3 *Gerta Köster, Technische Universität München, München GERMANY*
Validation of crowd models including social groups
- B.1 *Marco D'Orazio, Università Politecnica delle Marche, Ancona ITALY*
Analysis of pre-movement times for the evacuation of university classrooms in the event of fire
- B.2 *Anne S. Dederichs, Technical University of Denmark, Lyngby DENMARK*
Simulex simulations on the evacuation of day-care centres for children 0-6 years
- B.3 *Edwin Galea, University of Greenwich, London UNITED KINGDOM*
Modelling evacuation using escalators: A London underground dataset
- C.1 *Cecile Appert-Rolland, University Paris-Sud, Paris FRANCE*
Experimental study of pedestrian dynamics
- C.2 *Laure Bourgois, IFSTTAR, Paris FRANCE*
Pedestrian agent based model suited to heterogeneous interactions overseen by perception
- C.3 *Jan Dijkstra, Eindhoven University of Technology, Eindhoven NETHERLANDS*
Measuring individual's egress preference in wayfinding through virtual navigation experiments

The effect of integrating travel time

Tobias Kretz, PTV Planung Transport Verkehr AG, Karlsruhe GERMANY

SHORT ABSTRACT

This contribution demonstrates the potential gain for the quality of results in a simulation of pedestrians when estimated remaining travel time is considered as a determining factor for the movement of simulated pedestrians. This is done twice: once for a force-based model and once for a cellular automata-based model. The results show that for the (quality of) simulation results the question if estimated remaining travel time is considered or not is of higher relevance than the choice of the modeling technique force-based vs. cellular automata which normally is considered to be the most basic choice of modeling approach.

INTRODUCTION

It has recently been argued that there is a common problem of pedestrian simulation software” which is that most if not all available tools in the field overestimate the effective bottleneck a sharp corner (about 90° and more) imposes on a large group of (simulated) pedestrians (Rogsch & Klingsch, 2010). In other words: in simulations of pedestrian dynamics pedestrians cram too strongly when they move as a large group around a corner. Therefore they lose pace and in consequence time. The authors of said paper argue based on their experience and professional background as planners and applicants of simulation software that “No congestions have been observed in such cases (e.g. at the end of a football-match) based on corner movement.” Indeed while there appears to be no scientific quantitative investigation into the matter available, it is rather easy to find video footage of various such simulations on the web which supports the authors’ claim (Youtube, 2011).

The authors of said paper correctly observe that the problem stems from pedestrians receiving their main direction of movement (their desired direction) from a floor field or static potential which is calculated as distances from a spot to the destination. There is no reason to assume that the problem is resolved or even just partially resolved if navigation is based on a navigation graph.

It appears that at least so far there is no model in which the interactions between pedestrians can fully compensate a desired direction which is computed in such a way. It is argued here without proof that the reason for this is that nearly all models of pedestrian dynamics are greedy algorithms (the property of local optimal choice is more obvious for cell than for force models, nevertheless any shortest path approach is implicitly a greedy approach if in fact smallest travel time is intended) which either have a cut-off distance of influences or – if influences range infinitely far – the interaction between two pedestrians is never related to their whole environment which consists of all the other pedestrians plus their relative position and movement with regard to the destination. Claiming that the latter is a problem means to demand that somehow Sherif’s observation that “the properties of any part are

determined by its membership in the total functional system” needs to be considered in models of pedestrian dynamics, at least for the simulation of a subset of situations (Sherif, 1936).

FROM SHORTEST TO QUICKEST PATH MOVEMENT PARADIGM

Recently two related methods have been introduced which achieve what has been found to be desirable in the previous section. Both have in common that first for small areas a time delay is estimated if – hypothetically – a pedestrian would walk over that spot. The time delay in both methods is calculated from that this spot is currently occupied by a pedestrian. In one of the two methods the movement direction of that pedestrian has an impact on the value of estimated time delay. Second, these –small-area-time-delays are integrated (or better: summed up) starting at the destination and therefore carrying information about jams (roughly) upstream. The resulting field (called “dynamic potential” or “dynamic distance potential field”) is used in the next simulation time step.

The integration method as well as the application of the field in the simulation is different in both approaches. The details of the methods and especially their differences cannot be described within the scope of this abstract. We need to refer to the original publications: the first of the two approaches (Kretz, 2009) has been connected to a cellular automata-based model (Kretz & Schreckenberg, 2006), the second one (Kretz, Große, Hengst, Kautzsch, Pohlmann, & Vortisch, in print) has been combined with the Social Force Model as published in (Johansson, Helbing, & Shukla, 2007). The message in a bottle for both approaches is that the main or desired direction is no longer calculated based on the shortest path, but into the direction of estimated least remaining travel time, based on the attempt of a realistic estimation of the options of an individual within an environment of static obstacles and moving – as individuals or crowds – pedestrians.

Making pedestrians preferably move time step per time step into a direction of estimated least remaining travel is labeled here the “quickest path paradigm”.

EFFECTS

Using both models a simple scenario as given in (Rogsch & Klingsch, 2010) is simulated; both with shortest path as well as quickest path movement paradigm. Furthermore the same is done with a non-trivial geometry which could occur as such in a, however simple, real-world application. By varying the parameters of the original dynamics model as well as the dynamic potential calculation it is shown that the major impact and improvement comes from the decision if the quickest path paradigm is applied or not. With regard to the decade-long discussion on the pros and cons of the cellular automata vs. the force approach on pedestrian dynamics this is considered to be a remarkable result.

REFERENCES

- Johansson, A., Helbing, D., and Shukla, P. K. (2007). *Specification of the Social Force Pedestrian Model by Evolutionary Adjustment to Video Tracking Data*. *Advances in Complex Systems* . arxiv.org/abs/0810.4587
- Kretz, T. (2009). *Pedestrian Traffic: on the Quickest Path*. *Journal of Statistical Mechanics: Theory and Experiment* . arxiv.org/abs/0901.0170
- Kretz, T., and Schreckenberg, M. (2006). *The F.A.S.T.-Model*. ACRI 2006. Perpignan: Springer Berlin Heidelberg. arxiv.org/abs/0804.1893

Kretz, T., Große, A., Hengst, S., Kautzsch, L., Pohlmann, A., & Vortisch, P. (in print). Quickest Paths in Simulations of Pedestrians. *Advances in Complex Systems* . arxiv.org/abs/1107.2004

Rogsch, C., and Klingsch, W. (2010). *Basics of Software-Tools for Pedestrian Movement—Identification and Results*. *Fire Technology* .

Sherif, M. (1936). *The psychology of social norms*. Harper.

Youtube. (2011). Video Footage from various users: youtu.be/49HIZbFLPhg, youtu.be/jtKkHJXUVQY, youtu.be/LodYbDco0jY, and youtu.be/1WqnQjwAAac. James, John (1953): *The Distribution of Freely-Forming Small Group Size*. In: *American Sociological Review*, vol. 18, 569–570.

On modeling groups in crowds: empirical evidence and simulation results including large groups

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Research on pedestrian movement strives to mitigate risks at large events or public infrastructures by better understanding the flow of a crowd. Social scientists and mathematical modelers work towards this goal from different perspectives relying on the tools of their trade such as surveys and observational experiments on the one hand and mathematical formulations suitable for computer simulations on the other hand. In this paper both aspects will be combined to improve the modeling of groups in crowds with a special focus on the kind of crowd that one expects to attend national soccer league games. More precisely we are interested in regional evacuation around the soccer stadium in Kaiserslautern/Germany.

In the course of our work special attention has been drawn to the potential impact on social groups within crowds. In general, investigating and modeling groups has become a new focus of crowd research triggered by the knowledge that mass dynamics cannot solely be explained by the behavior of single members of the crowd. Helbing et al. (2000) assume “a mixture of socio-psychological and physical forces influencing the behavior in a crowd”. Today there is evidence, both empirical and from computer simulations, that social groups in a crowd have a very significant impact on pedestrian flow and thus on critical parameters such as evacuation times (Moussaid et al., 2010, Köster et al., 2011). The physical part of this effect is easily explained by the fact that persons who stick together form bigger particles in a granular type of flow thus hindering the progress of evacuation.

It is very important to know that the members of a social group try to stay together even in, or rather especially in, potentially dangerous situations. In fact, making contact with affiliated persons takes precedence over individual flight (Sime, 1983). The loss of companions and uncertainty about their well-being has a destabilizing effect for people affected by disaster, whereas the presence of companions is reducing fear (Mawson 2005). In our case we are looking at “psychological crowds” like fans in a soccer stadium with a strong spirit of togetherness (Drury and Cocking, 2007). If social groups accidentally break up during the evacuation process, these strong ties between the group members might hinder a fast flow. People might even turn against the stream of fleeing people in order to search for lost companions.

So far modeling research has concentrated on small groups of 2 to 5 persons neglecting larger groups. But soccer fans, our group of interest, often visit soccer games in a group of 5 and more people, e.g. friends, relatives, colleagues and fan clubs. This poses the following questions: Do we also need to model large groups in crowds? Do large groups occur frequently enough to have an impact? Or is it perhaps sufficient to consider smaller subgroups? What might the impact be especially in a crisis situation? In this paper we look at these questions from a sociological and a modeling perspective.

At the same time distributions of group sizes have yet to be investigated. Using a Poisson type distribution has been suggested (Coleman and James, 1961; James, 1953) and is certainly convenient for implementation, but is it realistic?

This paper is a joint effort by social scientists and mathematical modelers within the REPKA research project (Regional Evacuation: Planning, (K)Control, and Adaptation) to shed light on these areas. Empirical surveys (interviews and observations) have been conducted by social scientists at large events, and in particular at a soccer game, to gather information on the occurrence and relevance of large groups. The surveys lead to first suggestions on distributions suitable as input for mathematical modelers. The empirical results suggest that groups dominate the crowd at least for the sports events we are investigating. Visitors come with friends and relatives and only very rarely alone. There is evidence that especially larger groups do occur and should not be neglected. We also ascertain in our first observations that larger groups split up into subgroups. They maintain a loose coherence, which has another impact than independent small groups.

Realizing this, we certainly have to better understand what impact the crowd composition has in case of an evacuation. Is there a possibility that new unexpected bottlenecks emerge because group members stick together? Is it possible that known bottlenecks are so severely aggravated that escape routes are blocked? In a first attempt to answer these questions, mathematical models explicitly realizing different crowd compositions (small and large groups) are an appropriate approach. Four types of crowds are compared: aggregated crowds that consist entirely of individuals, crowds that include small groups, crowds that are composed of large groups that split up in subgroups and crowds composed of individuals, small groups and large groups according to the empirical distribution obtained by the surveys. Here we concentrate on a sample situation where two pedestrian streams cross. Our results demonstrate that not only groups in general but also larger groups in particular affect the flow of a crowd. The larger the groups are the less homogeneous the flow becomes.

We hope that this work will help and encourage further investigations concerning groups in crowds. A next step might be to look at groups with special characteristics like handicapped persons or groups with special purposes such as rescue teams walking towards the source of the danger instead of fleeing from it.

REFERENCES

Coleman, James S.; James, John (1961): *The Equilibrium Size Distribution of Freely-Forming Groups*. In: *Sociometry*, vol. 24, 36–45.

Drury, John; Cocking, Chris (2007): *The mass psychology of disasters and emergency evacuations: A research report and implications for practice*. University of Sussex, Department of Psychology. Brighton.

Helbing, Dirk; Farkas, Illés J.; Vicsek, Tamás (2000): *Simulating dynamical features of escape panic*. In: *Nature*, vol. 407, 487–490.

James, John (1953): *The Distribution of Freely-Forming Small Group Size*. In: *American Sociological Review*, vol. 18, 569–570.

Köster, G., Seitz, M., Treml, F., Hartmann, D., Klein, W.: *On the influence of group formation in a crowd*, *Journal of Contemporary Social Science*, in print, to appear 2011/12

Mawson, Anthony R. (2005): *Understanding Mass Panic and Other Collective Responses to Threat and Disaster*. In: *Psychiatry: Interpersonal and biological processes*, vol. 68 (2), 95–113.

Moussaïd M, Perozo N, Garnier S, Helbing D, Theraulaz G (2010): *The Walking Behaviour of Pedestrian Social Groups and Its Impact on Crowd Dynamics*. *PLoS ONE* 5(4): e10047. doi:10.1371/journal.pone.0010047.

Sime, Jonathan D. (1983): *Affiliative Behaviour during escape to building exits*. In: *Journal of Environmental Psychology*, vol. 3 (1), 21–41.

Validation of crowd models including social groups

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The development of group models within models of pedestrian motion has recently become a new focus of research. This interest was triggered by insight from the social sciences: Small groups often dominate the crowd at large events (Aveni, 1977) and the need to associate with family and friends may dominate over flight instincts (Sime, 1983; Aguirre et al., 1998). So far models of small subgroups have been suggested that well capture the movement towards a supposed common goal and ensure a certain spatial structure of the groups for easy communication (Moussaïd et al. 2010, Köster et al., 2011). It has been shown by both, simulations and measurements that the existence of subgroups in a crowd significantly impacts the behavior crucial for the safety of the crowd such as the flow at a given density or egress times when facing a bottleneck (Moussaïd et al. 2010, Köster et al., 2011). It is therefore desirable that crowd simulators adopt the new group models to better mitigate risks for example at large events or at public infrastructures.

However, to make this feasible reliable validation tests must be made available. Developers and users alike should be able to check whether the adopted model indeed captures the essential characteristics of a crowd composed of subgroups. As a desirable side effect, common validation tests would make simulation tools easier to compare and their range of application easier to assess. This can help to ensure a minimum quality standard and thus to further mitigate risks. In this paper we build on some basic tests suggested by Köster et al. (2011) for small subgroups and complement them by tests suitable for larger groups that split into subgroups.

The first step towards our goal is to agree on what a social group in a crowd is. In this paper we restrict ourselves to describe group characteristics that impact the flow of a crowd and hence quantities, such as the egress time at a bottleneck, which may be critical for crowd safety (Köster et. al., 2011). We present this very basic model of subgroups in a crowd for both small subgroups and larger groups in the form of a list of requirements so that the choice of implementation remains free. Hence the tests can be used for social force models, cellular automata and other model choices alike.

We then suggest a number of basic tests. Typical questions are: Do groups stay together? Do groups keep their velocity when walking along a free path? Do group members walk abreast as suggested by social communication models? Are they capable of splitting and reuniting while navigating around an obstacle like a column? Do larger groups split up into subgroups as suggested by social scientists (James, 1951)? Do they still stay together as a whole? Most of our tests are qualitative in their nature and can be conducted by producing snapshots or short videos from the simulation output. In a number of cases it is also possible to introduce heuristic measurement parameters that allow running the tests in the manner of automatic JUnit tests that are either passed or failed. This greatly simplifies consistent

development and testing.

Qualitative tests that are usually visual are very important as a starting point: a simulation tool that fails to ensure group cohesion, for example, cannot be considered reliable. However it is very difficult to compare different models and assess their range of application on visual observations only. This is what makes quantitative tests where an important output parameter is measured and compared against measurements from field or laboratory experiments so valuable. For aggregate crowds the perhaps most important quantitative test is based on the density-velocity or equivalently density-flow relationship in a moving crowd. So-called fundamental diagrams express how the crowd slows down with increasing density. Oberhagemann (2010) presented graphs of fundamental diagrams for small groups in crowds extracted from field studies. We propose tests based on these findings. However, since the results of the field study are not yet given in a numeric form, these tests are not yet truly quantitative. The authors therefore conducted a laboratory experiment where students are observed leaving a classroom as individuals, in pairs and in groups (Köster et al. 2011).

We demonstrate the feasibility of all suggested tests with our own simulation model that is based on a cellular automaton.

REFERENCES

Aguirre, B. E., Wenger, D. & Vigo, G. (1998) *A test of the emergent norm theory of collective behaviour*, *Sociological Forum*, 13(2), 301–320.

Aveni, A. F. (1977) *The not-so-lonely crowd: friendship groups in collective behavior*, *Sociometry*, 40(1), 96–99.

James, J. (1951) *A Preliminary Study of the Size Determinant in Small Group Interaction*, *American Sociological Review*, 16(4), pp.474-477

Köster, G., Seitz, M., Treml, F., Hartmann, D., Klein, W., *On the influence of group formation in a crowd*, *RSOC Journal of Contemporary Social Science*, in print, to appear 2011/12

Köster, G., Seitz, M., Treml, F., Pfaffinger A., *How to validate group models in pedestrian stream simulators: a proposal for basic tests*. *International Conference on Operations Research*, Zürich, September 2011

Moussaïd M, Perozo N, Garnier S, Helbing D, Theraulaz G (2010): *The Walking Behaviour of Pedestrian Social Groups and Its Impact on Crowd Dynamics*. *PLoS ONE* 5(4): e10047. doi:10.1371/journal.pone.0010047.

Oberhagemann, Dirk. *Risiko "Veranstaltungen": Planung, Bewertung, Evakuierung, Rettungskonzepte*, *VdS Conference Proceedings*, 2010.

Sime, J. D. (1983) *Affiliative behaviour during escape to building exits*, *Journal of Environmental Psychology*, 3(1), 21-41.

Analysis of pre-movement times for the evacuation of university classrooms in the event of fire

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Many studies show that people carry out activities not directly connected with the evacuation after hearing a fire alarm: they try to interpret the information about the hazard by interacting with other individuals; they wait to be reunited with other people; they waste time trying to retrieve objects, and they do not go towards the nearest exit but to the one where they entered the room. This type of behavior may slow down or impede the evacuation of the building thereby increasing the risk of loss of life in the event of a fire. In some types of buildings, this risk is particularly high. For example, the problem is typical in schools and universities, where there is both overcrowding during the hours of lessons and widespread use of electronic devices (notebooks, tablets) as learning instruments. Moreover, in these buildings some of the above mentioned types of behavior (waiting, retrieving belongings, etc.) may occur more frequently.

Several studies have been conducted on social factors that influence the „evacuation time“ of a building during a fire. A review of these studies was conducted recently by Kobes et al. (2010).

D. Helbing, I Farkas (2009); D. Helbing, I Farkas (2000) describe such behavior in terms of attractive and repulsive social forces that lead individuals to achieve their goal (evacuation time) on the basis of interactions with other people and the environment. Although this formulation is generally recognized, and used for commercial and research software, Zheng et al. (2009), Ko et al. (2007), showed that before people really move there is a phase called “pre-movement”, defined as the time in which individuals perform actions preliminary to moving: they try to interpret any information received about the dangers by interacting with other individuals present; they are wait for other people; they try to retrieve things to which they are attached. Analyses carried out on people’s behavior during previous incidents, show that this phase delays the evacuation and that it has caused numerous deaths (Purser e Bensilum (2001), McConnell et al. (2010), Kuligowski e Mileti (2009)). Purser e Bensilum (2001) analyze in detail the behavior of people during this phase in a series of fires. On the basis of their analysis, these authors show how the pre-movement process can be divided into two stages: “recognition” (when people continue their activities) and “response” (when people carry out activities prior to evacuation).

Since the “pre-movement time” strongly influences the overall evacuation time, several experiments have been conducted with the aim to quantify this value in offices, Oven e Cakici (2009), stores, Shields e Boyce (2000), hotels, Kobes et al. (2010), cinema and theaters, Nilsson e Johansson (2009), schools, Liu et al. (2009), Zhang et al. (2008). On the basis of experimental data, Purser e Bensilum (2001) report the average response time for the „recognition“ and „response“ phases in different types of building. In particular, they show an average time ranging between 0.03 to 1.05 (decimal minutes)

for the „recognition phase“ and between 0.13 and 0.67 (decimal minutes) for the „response phase“. The maximum “pre-movement” time measured in experiments is 3.92 decimal minutes for a theater (from the voice announcement).

However, the data reported by Purser e Bensilum (2001) show a wide dispersion, depending on the type of building and on the activities in which the people are engaged, Liu e Lo (2011). In fact, some authors agree that, although the “pre-movement time” could be exemplified as an explicit value, it is a random variable following some kind of probability distribution. Purser e Bensilum (2001) suggest a unimodal distribution characterized by a positive skewness. Normal and lognormal distributions are also given.

Finally, studies by various authors agree in highlighting how the “pre-movement” time can vary significantly depending on the type of building and the activities in which people are engaged. Furthermore, the authors show that the “pre-movement” time could be significantly influenced by the phenomena of “attachment to people” (waiting to be reunited with family members and friends) and “attachment to things” Zheng et al. (2009). Although the latter is recognized to be a major cause of delay in people’s movement in the event of evacuation this aspect has not yet been sufficiently investigated, as indicated by Kobes et al. (2010). Therefore it was considered necessary to further investigate this issue by conducting a simulated evacuation experiment in university classrooms. In the experiment we evaluated the influence of “attachment to things”, in particular to electronic devices (notebooks, tablets) that are now commonly used in these environments for educational activities. Moreover current teaching methods make increasing use of these devices in classrooms and, therefore, the evacuation of a school building may be strongly affected by this factor. The results are compared with previous studies conducted by Zhang et al. (2008).

In this study we analyze the behavior of two groups of students in a Faculty of Engineering, following the activation of a fire alarm. The study shows that in these types of buildings, due to the fact that students are involved in activities with electronic devices, “pre-movement times“ are very high and are strongly influenced by users’ attachment to their belongings. In particular this study allows the distribution of pre-movement time and the speed of people during the evacuation to be calculated. The study confirmed the behavior reported in the literature characterizing the initial stages of evacuation in the event of fire. In particular, we detected the existence of a „recognition phase“ (in which individuals continue with their activities) and a „response phase“ (in which individuals perform preparatory work: turning off electrical equipment, etc .).

In particular we show how these activities, at universities, because of the introduction of teaching methods that use personal electronic devices, affect the „pre-movement“ time and also represent an obstacle for the rapid evacuation of students who did not wish to proceed before saving their data and tools.

Specifically, we confirm that the „pre-movement time“ measured can be described by a Weibull-type distribution with a positive skewness .

Simulex simulations on the evacuation of day-care centres for children 0-6 years

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Performance based codes are successively introduced across the world [Fleischmann, 2011]. Applying the methods of fire safety engineering requires models describing the evacuation of people from buildings [Frantzich, 1994]. Data from evacuation experiments are used for validation and adjustments of such models [Kuligowski et al., 2010]. Children account for 15-20% of the western world's population [Larusdottir et al., 2010; Nordic statistical yearbook, 2009] and evacuation models should be validated using data taken from this group in order to ensure the safety of this population and to fulfill the growing demand on "equal egress". One of such models frequently applied in fire safety engineering is Simulex [Thompson et al., 1994, 1995]. The model is widely applied within fire safety design. The model is designed also to model evacuation of children.

The purpose of the current study is to compare the results from simulations with Simulex 1.2. [Frantzich, 1998] on the movement of children in the age 0-6 years during an evacuation with real data from experiments [Larusdottir et al., 2010]. Comparisons of total evacuation times are shown and discussed in this abstract, walking speeds on horizontal plane and on stairs are discussed in this abstract, the results of flow through doors and walking speeds on horizontal plane and on stairs will be presented and analyzed in the proposed paper.

Computer simulations applying Simulex 1.2 of 9 different day-care centres are carried out. In Danish day-care centers children at the age of 0-6 years are divided into two groups: younger children at the age of 6 months to 2 years and older children at the age of 3 to 6 years, i.e. crèche and kindergarten. The results of the simulations are compared with data from real experiments from evacuation exercises [Larusdottir et al., 2010] at the same day-care centres.

Following general assumptions are given in Simulex:

- Each person is assigned a normal unimpeded walking speed
- Walking speeds are reduced as people get closer together
- Each person heads towards an exit by taking a direction which is at right angles to the contours shown on the chosen distance map
- Overtaking, body rotation, sideways stepping and small degrees of back-stepping are all accommodated.

In the simulations carried out within the current study occupants are defined as children only. In the simulations, all the children are walking since it is not possible to specifically define running children. Furthermore, Simulex does not differentiate between different age groups; occupants are just defined as children.

The day-care centers have three spiral stairs. In the model the stairs are defined with the true length of the staircase, the slope length added the length of the landings. The width of the spiral stair should be defined so narrow that it is not possible for occupants to overtake each other. Stairs are shown as straight stairs [Frantzich, 1998].

The egress time is defined as the time from the first occupant starts moving, until the first occupant respectively the last occupant exits the day-care centre. Reaction and decision time are assumed to be neglectable due to the teachers' knowledge about the exercises. The warning times found in the exercises is added to the walking time. Figure 1 shows the total evacuation times from the simulations compared to the times found in the evacuation exercises.

The results show that the simulated times are lower than the times from the real data. This applies both to the times for the first person out and the last person out. However, there is a better compliance between the times for the first person out which could also be expected. The small gap between simulation and experiment can partly be explained by the fact that the reaction and decision time are neglected. The difference between the times for the first person out in the exercises respectively Simulex varies between 7 seconds and 56 seconds. The difference on 56 seconds is for a day-care centre where the children put on outerwear before leaving the building.

Results of the walking speed in horizontal plane will be shown in the proposed paper. The results from the exercises give a higher travel speed for the older children running than the average walking speed found in Simulex. The travel speed for the younger children running complies well with the average walking speed found in Simulex. However, only a few children and not enough consistency to use the numbers in e.g. a design phase for a building. Furthermore, the spread of the experimental data of the travel speeds is larger than from the simulations. Except for the few children running, the walking speed found in the simulations in Simulex is higher than the walking speed found in the exercises for both age groups. The walking speeds from the simulations correspond better with the results from the exercises for children running but still not completely.

Familiarity with the escape-route mattered with respect to travel speed along the three stairs. It is not possible to simulate occupant's knowledge and familiarity to a given stair. Except for the initial escape in the familiar staircase, the simulations overestimate the travel speed on stairs.

REFERENCES

Frantzich, H., *En modell för dimensionering av förbindelser för utrymning utifrån funktionsbaserade krav*, Tech. rep., Department of Fire Safety Engineering, Lund University, (In Swedish) (1994).

Frantzich, H.: „Användarmanual till Simulex ver 1.2“, Inst. för brand-teknik, Lund University, Sweden (1998)

Fleischmann, C.M., *Is Prescription the Future of Performance Based Design?*, IAFSS Symposium Maryland, 2011

Kuligowski E. and Peacock R., *A review of building evacuation models*, National Institute of Standards and Technology Technical Note 1471, 2010, 156pp.

Larusdottir, A.R. and Dederichs, A.S., (2010) *Evacuation of Children: Movement on Stairs and on Horizontal Plane*, *Fire Technology special issue*. <http://dx.doi.org/10.1007/s10694-010-0177-6>

Nordic statistical yearbook, Nordic Council of Ministers, Nordic Council, 2009.

Thompson, P. A. & Marchant, E. W. (1994). *Simulex; Developing New Computer Modelling Techniques for Evaluation*. In *Fire Safety Science -- Proceedings of the 4th International Symposium* (pp. 613-624).

Thompson, P. A. & Marchant, E. W. (1995). *Testing and Application of the Computer Model ,Simulex'*. *Fire Safety Journal*, 24, 149-166.

Modelling evacuation using escalators: A London underground dataset

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The development and expansion of underground (subway) stations, often located deep underground, has been possible with the introduction of escalators capable of efficiently transporting large volumes of people [1]. As a result, underground stations are reliant upon escalators for circulation and in many cases emergency evacuation. Despite this, few studies have attempted to quantify human factors associated with escalator usage (microscopic analysis), the majority of past studies focusing on establishing capacity (macroscopic analysis) rather than usage behaviours [2-4]. As such, it is uncertain how human factors associated with escalator usage impact escalator performance in both circulation and evacuation situations. It is also uncertain whether human factors associated with escalator usage has a cultural component. To address these issues, escalator human factors data within three underground stations in Spain (Barcelona) [5], China (Shanghai) [6] and England (London) have been collected. In each location the same methodology for data collection and analysis was used. This paper presents an overview of the analysis for the English dataset. Furthermore, using the data collected along with the newly developed escalator model available within the buildingEXODUS evacuation software [6, 7], a series of evacuation scenarios of a hypothetical underground station are presented. The evacuation analysis is intended to explore the impact of using escalators with a variety of realistic human factors.

The human factors data collected relates to escalator/stair usage, walker/rider usage, side usage, walker speeds and boarding flow-rates. In total, data relating to 11,019 pedestrians was collected: 6,123 using escalators and 4,896 using an adjacent stair. Analysis of the data shows that the majority of pedestrians (67.0%) elected to use the escalator in the up direction. However, in the down direction the majority of pedestrians (65.3%) elected to use the adjacent stair. This suggests that direction of travel influences escalator/stair selection. A number of evacuation/circulation models that have an escalator capability utilise simplistic measures to determine if pedestrians elect to use an escalator or adjacent stair. In most cases, pedestrians are either forced to use a device, or select a device which minimises travel time. Based on the data collected, clearly this is not always the case. Approximately three quarters of pedestrians (74.9%) rode the escalators with the remaining electing to walk. A higher proportion of walkers were observed during the rush-hour compared to the non-rush hour. This suggests that trip purpose and subsequent levels of motivation influence escalator walker/rider choice. The proportion of walkers/riders will determine the flow-rate achieved upon an escalator. As with escalator/stair choice, without this type of data, many evacuation/circulation models ignore this microscopic behaviour and impose macroscopic data such as maximal flow-rates on escalator performance. Analysis of the side usage data identified that there was a common side preference for riders to typically use the right side (88.4%) and walkers to use the left side (78.2%) of each escalator ($p < 0.05$). Overall average walker speeds were faster in the down direction (0.82m/s) than in the up direction (0.70 m/s) ($p < 0.05$).

However, there was no significant difference between walker speeds during the rush-hour and non-rush hour periods. Unlike the walker/rider choice, this suggests that trip purpose and subsequent levels of motivation are of little influence upon escalator walker speeds. The maximum escalator flow-rate recorded was 75 ped/min in the up direction during the morning rush-hour period. This is considerably less than maximal flow-rates reported in past studies [2].

Using the data collected from the London underground, a series of 14 underground station evacuation scenarios were conducted exploring the influence of escalator strategies and associated human factors upon an evacuation. The evacuation analysis investigated the impact of a variety of escalator human factors including device selection, walker/rider selection, side usage, and escalator/stair availability. The building used for the simulations was a hypothetical 2 level underground station (platform and ticket hall level) connected via a series of escalators and stairs. In total, 3,856 agents were represented in the station: 2,892 on the platform level and 964 on the ticket hall level above.

Results from the analysis suggest that even the provision of static escalators can have a considerable influence upon an evacuation compared to using stairs alone. It is noted that in some cases, escalators – even static escalators – are not used in evacuation situations. Furthermore, the provision of a moving escalator was shown to decrease total evacuation times (TET) by up to approximately 25% compared to using stairs alone and around 10% compared to using static escalators. Results have shown that little decrease in TET was observed when all escalator users walked compared to if they all rode. As such, urging escalator users to ride on both sides of an escalator, maximising tread utilisation, may be advantageous during an evacuation considering the reduced likelihood of escalator users tripping compared to walking. During scenarios where escalators/stairs were rendered unavailable, as expected, had a considerable impact upon the evacuation. In those scenarios, increases in TET of up to 59.8% and platform clearance times of up to 71.6% compared to stairs alone were recorded. Such findings highlight the severity caused by the unavailability of escalators/stairs (e.g. due to fire/smoke, code stipulations, etc), and the need to consider additional provision of vertical egress capacity.

The data analysis provides insight into escalator human factors. It is a useful resource for evacuation/circulation model developers. The presented evacuation analysis demonstrates the potential impact of different escalator strategies and to what extent human factors influence these strategies. The study could potentially be used as a basis for engineering analysis where the performance of different procedural variants with regards to escalators are required to be explored.

REFERENCES

- [1] Strakosch, G., Caporale, R.S, (2010), *The Vertical Transportation Handbook, The Third Edition*, John Wiley and Sons Inc.
- [2] Al-Sharif, L., (1996), *Escalator Handling Capacity: Standards Versus Practice*, Elevator World.
- [3] Cheung, C., Lam, W., (1998), *Pedestrian Route Choices Between Escalator and Stairway in MTR Stations*, *Journal of Transportation Engineering*, Vol. 124, No. 3, pp227-285.
- [4] Davis, P., Dutta G., (2002), *Estimation of Capacity of Escalators in London Underground*, No 2002-11-01, IIMA Working Papers from Indian Institute of Management Ahmedabad, Research and Publication Department.

[5] Kinsey, M.J, Galea, E.R, Lawrence, P.J, Blackshields, D., Hulse, L., Day, R. and Sharp, G., (2008), 'Modelling Pedestrian Escalator Behaviour', *Pedestrian and Evacuation Dynamics (PED) Conference*, pp689-695.

[6] Kinsey, M.J, Galea, E.R, Lawrence, P.J, (2009), 'Extended Model of Pedestrian Escalator Behaviour Based on Data Collected within a Chinese Underground Station', *Proceedings of the Human Behaviour in Fire Conference*, pp173-182.

[7] Kinsey, M.J, (2011), 'Vertical Transport Evacuation Modelling', *PhD Thesis, University of Greenwich*.

Experimental study of pedestrian dynamics

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In the frame of a French project (PEDIGREE) involving four teams (IMT-Toulouse, INRIA-Rennes, CRCA-Toulouse, LPT-Orsay), we have performed several experiments to study the dynamics of pedestrians in various geometries.

Experiments were performed in-door, and each pedestrian was equipped with 4 markers which were detected by a VICON system (infra-red cameras). As a result, the full 3D trajectory of each pedestrian could be reconstructed, with a frequency of 120 frames/s.

In the frame of this project, several experiments were performed, including:

- 1 - 1d-motion along a circle [1,2,3].
- 2 - mono-directional and bi-directional flow in a ring corridor [4].
- 3 - oscillations at a bottleneck.
- 4 - Interactions between 2 or 3 individual trajectories.
- 5 - Interactions between incoming lines of pedestrians.

Then, as an illustration of the type of results that can be obtained from these experiments, we shall concentrate on the analysis of the 1d circle experiment.

Participants were asked to walk in a natural way along a circular path, without passing each other. Two different circular paths were used, with different radii (respectively 2.4 and 4.1 meters). The number of pedestrians was varied from 8 to 28, resulting in a global density ranging from 0.31 to 1.86 ped/m. However, the local densities could be lower or higher due to spontaneous formation of spatial inhomogeneities.

Before the start of the experiment, pedestrians were placed either at equal distances around the circle, or packed all together. Each experiment lasted 1mn (or slightly more for higher densities), and several replicas (up to 8) were realized for the same set of parameters, if possible with different sets of participants.

First some comparison with previous experiments [5,6] will be presented. Here, the fundamental diagram can be defined in several ways, depending whether the density and the velocity are taken as global, locally averaged or instantaneous quantities [1]. The initial conditions (homogeneous or jammed) turn out to have a short lived influence. The contributions to the fundamental diagram of stationary behavior or transient behavior due to rapid fluctuations will be discussed.

In previous experiments, the velocity-spatial headway relation was found to be linear. However, our experiment has allowed us to cover a much larger range of densities.

One of our main result is to show that there exist two clear transitions in the behavior of pedestrians, separating 3 dynamical phases [1]:

- Free flow regime: for a spatial headway larger than 3 meters, pedestrians walk with their preferred velocity;
- Weakly constrained regime: for a spatial headway between 1.1 and 3 meters, the velocity depends only weakly on the spatial headway.
- Strongly constrained regime: for a spatial headway less than 1.1 meter, the velocity depends strongly on the spatial headway.

In each phase, the velocity-spatial headway relation is linear, but the slope is differs from one phase to the other. This finding could open new perspectives in terms of modeling.

The transition between the weakly and strongly constrained regimes was already partially visible in previous experiments but was not interpreted as such, as lower densities were not explored. It has consequences on the way comparisons between different experiments should be performed, in order to extract some cultural influence on the walking behavior as in [7].

The oscillations of the radial coordinate allow to detect steps. We shall present systematically how the step frequency or amplitude vary with the parameters of the experiment, and extract some simple laws [2]. We show also that, as expected, synchronization of the steps may occur at high densities, but that this is not a general feature.

The knowledge of the full individual trajectories allows also to extract the stop and go waves that are produced at high densities. We can extract not only the propagation velocity of the waves, but also the damping of the signal inside the wave, the width of the wave, the characteristics of the pedestrians inside the wave, etc... The possibility to localize precisely the waves will enrich the discussion about the fundamental diagram.

The analysis of the following behavior observed for pairs of successive pedestrians has led to the proposal of a microscopic model [3]. It is possible to compare models and experiments either at the microscopic level, or at a macroscopic level, based on the characteristics of stop and go waves.

The data obtained from this experiment will be made available for the scientific community on a web platform in 2012.

REFERENCES

[1] A. Jelic, C. Appert-Rolland, S. Lemercier and J. Pettre. *Properties of pedestrians walking in line - the fundamental diagram, preprint, 2011.*

[2] A. Jelic, S. Lemercier, C. Appert-Rolland, and J. Pettre. *Properties of pedestrians walking in line - stepping behavior. In preparation, 2011.*

[3] S. Lemercier, A. Jelic, J. Hua, J. Fehrenbach, P. Degond, C. Appert-Rolland, S. Donikian, and J. Pettre, *A realistic model of following behavior for crowd simulation, submitted to Eurographics 2012.*

- [4] M. Moussaid, E. Guilloit, M. Moreau, J. Fehrenbach, O. Chabiron, S. Lemerrier, J. Pettre, C. Appert-Rolland, P. Degond, and G. Theraulaz. *Outbreak and breakdowns of collective intelligence in human crowds*. submitted to *PLoS Computational Biology*, 2011.
- [5] A. Seyfried, B. Steffen, W. Klingsch, and M. Boltes. *The fundamental diagram of pedestrian movement revisited*. *J. Stat. Mech.*, page P10002, 2005.
- [6] A. Seyfried, B. Steffen, W. Klingsch, T. Lippert, and M. Boltes. *Steps toward the fundamental diagram - empirical results and modelling*. In N. Waldau, P. Gattermann, H. Knoflacher, and M. Schreckenberg (eds), *Pedestrian and Evacuation Dynamics 2005*. Berlin, Springer, 2007.
- [7] U. Chattaraj, A. Seyfried, and P. Chakroborty. *Comparison of pedestrian fundamental diagram across cultures*. *Advances in Complex Systems*, 12:393-405, 2009.

Pedestrian agent based model suited to heterogeneous interactions overseen by perception

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INTRODUCTION

Heterogeneous crowd models are needed in some applications including education, entertainment, training (for the military and police) and human factors analysis for building evacuation, for sport events [7] and for military simulation (especially in case of urban warfare [5]).

Most of the work about pedestrian simulations concerns situations of homogeneous interactions as for planning and for designing in transportation studies. These studies assume that pedestrians broadly share common behaviour and goal (reaching out of a building, crossing a street ...). Excepted in military simulation and game, there is only few research where actors have antagonistic purposes. However these researches do not focus specially on elaborating a pedestrian moving model, but they rather treat of patrol optimization (where to send efficiently the police ...).

In order to model different interactions between pedestrians in complex and dynamic context/ situation, we propose an exploratory work about a flow of pedestrians in the presence of an immediate and shifting danger (a pacific demonstration with a military assault). We propose here an Agent based model with a hierarchical architecture driven by perception, articulated with a controller suited for various situations. The model is generic since it is used for pacific demonstrators and for control force member. We experiment a scenario where a control force squad try to catch some leaders in the crowd.

STATE OF THE ART

Microscopic models represent pedestrians with the mean of individual entities. These models include two major approaches: pedestrian subjected to forces [4] or to behavioural rules [8]. Other models try to encompass psychological features involved in high decision process of pedestrians.

Works of McKenzie aim to develop a tool with a set of models of military simulation with a credible crowd psychological [5]. Crowd-MAGS project [1] shares the same objectives. With a Multi Agent System approach, each pedestrian is modelled by an agent endowed with a set of complex behaviors (set of hierarchical rules).

Recent works [6] tackle the attractive forces between pedestrians in order reproduce the observed recurring patterns in groups. These researches assume that pedestrians are conscious of the group relationship.

Besides, precedent studies do not carry the many pedestrian interactions induced by a dynamical environment. Indeed, one alters the initial interaction based on his perception of the environment.

A HIERARCHIAL ARCHITECTURE

Our model takes place within the framework of perception-interpretation-selection-decision [10]. We note that the interpretation and selection process can be disconnected and the importance of decision feedback on those process. We follow [3]'s concept that distinguish 3 decision levels: strategic, (planning ...) tactical (section route choice ...), operational. (instantaneous motions ...). We propose a hybrid architecture driven by perception and we focus on the junction between tactical and operational level. The operational level may be controlled in different ways depending on the nature task to perform (crossing the street, escape ...).

PEDESTRIAN AGENT MODEL

Basically, we employ the widely used Social Force Model of Helbing moving agents [4]. A pedestrian agent acts as if it was subject to attractive forces (its destination ...) and repulsive forces (obstacles ...). It tries to trail straight ahead in order to reach its destination following a shortest path route, and avoiding obstacles. We enhanced this model with sensitivity measures and by introducing additional features [2].

We provide here pedestrian agents with different features in order to influence their perceived interaction and the way to manage them. In our example, a pacific demonstrator has to perceive other pacific pedestrians and obstacles and to differentiate them from some stationary danger and from some charging policemen; a control force member has to perceive the pedestrian "target" and other non-combatant pedestrians.

For monitoring the moving model, we propose an automata driven by perception. This tool allows for a pedestrian to escape from a danger (static, dynamic a predator for instance) and to get closer from other pacific demonstrator.

DISCUSSION AND PERSPECTIVES

After some experimentations (for calibrating some parameters of our model), we exhibit the emergence of group phenomenon. Our simulations take place in a corridor and in a bottleneck. We are able to compare our results with works like the ones of Venel [9] and those of Hoogendoorn [3]. However, even if there are some references for collective behaviour [11], we point out the lack of data about pedestrians.

More research is needed to better understand and to reproduce global behaviour for a group of pedestrians [6] on particular in the case of crowd dispersion in an urban warfare or in an emergency evacuation. Several problems arise like group identification or group formation.

REFERENCES

- [1] B. Moulin, B. Larochelle, *Crowdmags, Multi-agent Geo-Simulation of the interactions of a crowd and control forces, Modelling, Simulation and Identification, 2010.*
- [2] L. Bourgois, A. Oulhaci, J.-M. Auberlet, *Simulation de déplacement : Vers un modèle de perception et de prédiction du comportement d'autrui, JFSMA, 2010.*
- [3] S. P. Hoogendoorn, W. Daamen, *Pedestrian Behavior at Bottlenecks, Journal Transportation Science, 2005.*

- [4] A. Johansson, D. Helbing, P.K. Shukla, *Specification of the Social Force Pedestrian Model by Evolutionary Adjustment to Video Tracking Data*, *Advances in Complex Systems*, 2007.
- [5] F. McKenzie, M. Petty, P. Kruszewski, R. Gaskins Q.-A. Nguyen, J. Seevinck, E. Weisel *Integrating crowd-behavior modeling into military simulation using game technology*, *Journal Simulation and Gaming*, March 2008
- [6] M. Moussaïd, N. Perozo, S. Garnier, D. Helbing, G. Theraulaz, *The walking behaviour of pedestrian social groups and its impact on crowd dynamics*, *PLoS ONE*, 2010.
- [7] N. Pelechano, K. O'Brien, B. Silverman, N. Badler, *Crowd Simulation Incorporating Agent Psychological Models, Roles and Communication*, *1st Int'l Workshop on Crowd Simulation*, 2005
- [8] C.W. Reynolds, *Flocks, Herds, and Schools: A Distributed Behavioral Model*, *Computer Graphics, SIGGRAPH*, 1987.
- [9] J. Venel, *Integrating strategies in numerical modeling of crowd motion*, *Pedestrian and Evacuation Dynamics*, 2008.
- [10] D. Weyns, E. Steegmans, and T. Holvoet. *Towards active perception in situated multi-agent systems*, *Applied Artificial Intelligence*, 2004.
- [11] U. Weidmann, *Transporttechnik der Fussgänger, Transporttechnische Eigenschaften des Fussgängerverkehrs (Literaturauswertung) Schriftenreihe des IVT Nr. 90, Zweite, ergänzte Auflage, Zürich, März, 1993.*

Measuring individual's egress preference in wayfinding through virtual navigation experiments

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Finding one's way to a certain destination is one of the most compulsive behaviours in our daily life. This has been extensively studied in the last 50 years. Originally raised by Lynch (1960), the term "wayfinding" is defined by Golledge (1999) as "the process of determining and following a path or route between an origin and a destination." Arthur and Passini (1990) suggest that different types of information can be used in wayfinding tasks, namely the verbal (information obtained from the reception, staff members, etc.), the graphic (map of the environment, signage showing the location or pointing to a certain location, etc.), the architectural (e.g. doors, corridors, texture, elevators) (Dogu and Erkip 2000, Passini 1996), and the spatial (spatial relationship of objects in the environment) (Arthur and Passini 1992, Passini 1984). The significances of these types of information on wayfinding processes have been investigated. In most studies, however, the function of the architectural information was underestimated compared to other types of information-- it was often treated as limiting the architectural space.

In reality, human feelings about the colour of an object are influenced by different factors, such as the physical condition of the object, the colour contrast between the object and its background, our mental state at that moment, etc. Moreover, different colours have a different psychological effect for different people. In this study, a greyscale model is applied for differentiating different colours and to describe various psychological effects of colours by this greyscale model. Therefore, egress choices are only influenced by grey contrast between egresses, and between the egress and its background. This grey contrast represents the colour factor.

In this paper, a study will be presented where subjects' egress choices are collected given different settings of selected egresses (door or corridor) in a list of architectural spaces. In this context architectural spaces are independent spaces with only visual architectural information provided. The main objective of this study is to research the utility effect of variables that would influence individual's egress choices in architectural spaces. Moreover, it is assumed that a preference function can be deduced to predict the probability of an individual to choose the left egress of the egresses pair (left, right) in architectural spaces. A suggestion for this deduction will be done.

This paper focuses on the individual's egress choosing behaviour in the built office environment. Note that "egress" mentioned in this paper is specified as a linkage between rooms, or a linkage between a room and a space, rather than the linkage between a built environment and the world out of this built environment. After a study on the egress types in the office environment, two common used egresses are selected for the experimental design: door and corridor. In addition, three different sizes are designated for each assigned egress referred to as narrow (80cm by 200cm), normal (150cm by 200cm),

and large (194cm by 246cm).

Four characteristics are identified for these two egress types, which could influence visitor's choice on the egresses, resulting in the deduction of four variables for designing the rooms in the experiment: the distance from the egress to the entrance point (D), the width of the egress (W), the grey level of the egress (G), and the angle between the view direction and the egress in the view (A). The grey level of an egress is computationally defined, ranging from 0 to 100, indicating the brightness of the grey of the egress. The change of room illumination in the virtual built environment would affect the grey level of the egresses. The higher the grey level of an egress, the brighter of the egress's grey will be.

The type of room is another related variable, which is also taken into account in the experimental design phase. In the experiment, each designed room consists of two egresses. As a result, there are three types of room layouts: a room with two corridors, a room with two doors, and a room with a door and a corridor.

The designed rooms are of three different sizes, namely small (4m by 6m), medium (9m by 12m), and large (15m by 20m). Each designed room contains two egresses: one on the left, and one on the right. The orientations of the egresses in these rooms vary systematically. The experiment is VR application based. Therefore the aspect ratio of the screen is preset such that the application could be run on any computer with the same aspect ratio. Based on the variable levels of the egresses and types of the rooms, fractional factorial design is employed to determine the number of convex rooms that is required for the experiment. The sequential order of the rooms presented in the experiment is randomly generated for each subject once they start the experiment. In this experiment, as long as one subject chooses an egress in the current room and within a certain distance to the chosen egress, the next room would be generated and linked to the chosen egress automatically according to the generated sequential order of the rooms for this subject.

From the analysis one can conclude that visual architectural information has a significant utility effect on individuals' behaviours. This paper will present the experimental design, the data collection, and the outcomes of the utility effects as well as the suggestion for the utility function.

Oral presentations

Wednesday, 6 June - 11.40

- A.4 *Edwin Galea, University of Greenwich, London UNITED KINGDOM*
An evacuation validation data set for large passenger ships
- A.5 *Hermann Mayer, Siemens AG, München GERMANY*
Influence of emissions on pedestrian evacuation
- A.6 *Christian Rogsch, RiMEA e.V., Neustadt GERMANY*
RiMEA - A way to define a standard for evacuation calculations
- B.4 *Mojdeh Nasir, Deakin University, Melbourne AUSTRALIA*
Fuzzy prediction of pedestrian steering behaviour with local environmental effects
- B.5 *Ekaterina Kirik, Institute of Computational Modelling RAS, Novosibirsk RUSSIA*
Fundamental diagram as a model input – direct movement equation of pedestrian dynamics
- B.6 *Francesco Zanlungo, Advanced Telecommunication Research Institute, Kyoto JAPAN*
Experimental study and modelisation of pedestrian space occupation and motion pattern in a real world environment
- C.4 *Laura Künzer, Friedrich-Schiller-Universität Jena, Jena GERMANY*
Psychological aspects of german signal words in evacuation warnings
- C.5 *Tomoichi Takahashi, Meiji University, Tokyo JAPAN*
Effect of guidance information and human relations among agents on crowd evacuation behavior
- C.6 *Felix Cabrera, Pontificia Universidad Catolica del Peru, Lima PERU*
Using the social force model to represent the behavior of pedestrians at chaotic intersections of developing countries: the case of Peru

An evacuation validation data set for large passenger ships

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In 2002 the International Maritime Organisation (IMO) introduced guidelines for undertaking full-scale evacuation analysis of large passenger ships using ship evacuation models [1]. These guidelines, known as IMO MSC Circ. 1033, were to be used to certify that the passenger ship design was appropriate for full-scale evacuation. As part of these guidelines it was identified that appropriate full-scale ship based evacuation validation data was not available to assess the suitability of ship evacuation models. As suitable validation data was not available, a series of test cases were developed which verified the capability of proposed ship evacuation models in undertaking simple simulations. However, these verification cases were not based on experimental data. Furthermore, successfully undertaking these verification cases does not imply that the evacuation model is validated or capable of predicting real evacuation performance. In 2007 IMO MSC Circ. 1238 [2], a modified set of protocols for passenger ship evacuation analysis and certification were released however, the issue of validation of passenger ship evacuation models was not addressed. The IMO Fire Protection (FP) Sub-Committee in their modification of MSC Circ. 1033 at the FP51 meeting in February 2007 [3] invited member governments to provide, "...further information on additional scenarios for evacuation analysis and full scale data to be used for validation and calibration purposes of the draft revised interim guideline." The EU framework 7 project SAFEGUARD aims to address this requirement by providing full-scale data for calibration and validation of ship based evacuation models.

As part of project SAFEGUARD, five passenger response time data sets and five full-scale validation data sets from three different types of passenger vessels have been collected. This paper will concentrate on the first data set collected from the large RO-PAX ferry operated by ColorLine AS called SuperSpeed 1 [4]. The vessel can carry approximately 2000 passengers and crew and over 700 vehicles. The route taken by the vessel is from Larvik in Norway to Hirtshals in Denmark, a trip of 3 hours and 45 minutes. The ship contains a mixture of spaces spread over three decks including; business and traveller class seating areas (airline style seating), large retail and restaurant/catering areas, bar areas, in-door and out-door general seating areas and general circulation spaces. Data from a sailing from Larvik to Norway in early September 2009 was collected with 1349 passengers on board. The trial consisted of the ship's Captain sounding the alarm and crew moving the passengers into the designated assembly areas. The trial took place at an unspecified time on the crossing however, passengers were aware that on their crossing an assembly exercise would take place. The data collected during the assembly trial consisted of passenger response time data and a comprehensive validation data set for ship based evacuation models. Some 30 digital video cameras were used to collect the response time data. The validation data was collected using a novel data acquisition system consisting of ship-mounted beacons, each emitting unique Infra-Red (IR) signals and data logging tags worn by each

passenger [4]. The validation data set consists of starting locations of passengers, arrival time at the designated assembly locations and the paths taken by the passengers.

This paper will present the results generated by the IR logging system and some validation analysis undertaken to demonstrate that the IR system provides an accurate representation of the arrival times at the assembly stations. This is based on comparisons of measured IR arrival times with that of arrival times measured using video data. The results of this analysis confirm that the IR logging system can provide a very accurate measure of arrival times for large crowds of people.

The result of the assembly exercise is an assembly curve which plots the arrival time of each passenger into the assembly stations. As such the evacuation model validation exercise will measure the ability of the evacuation model to predict the overall assembly curve – not simply the overall assembly time. It is noted that for this exercise, the total assembly time was approximately 10 minutes. In principle this data set is ideal for validation purposes, as the starting locations and response times of each participant is known. This means that it should be possible to remove most of the uncertainty associated with input parameters associated with response time and starting location.

Unfortunately, the situation was not as ideal as envisaged. First, of the 1349 passengers on board, 780 wore the IR tags and participated in the assembly trial. The majority of the 569 passengers who did not take the tags indicated that they did not want to participate in the assembly exercise – which was not compulsory for ethical and legal reasons. However, of the 569 passengers who did not take tags, a significant number (as determined from the analysis of video footage) did eventually decide to participate in the assembly exercise. By participating in the trial, the presence of the untagged individuals in the evacuation routes will have had an impact on the overall evacuation, especially in the highly congested areas. However, their assembly times will not have been recorded in the overall assembly curve. Secondly, the exact location of the tagged people was not known, but the region that they were located in was known. Spatial regions were between 24m and 48m long; thus not knowing the precise starting location of an individual may have increased/decreased their arrival time by 25-50 seconds. Furthermore, the response time is not associated with a unique individual but to a region. Thus the precise response time of each unique individual is not known, but the response time distribution associated with a starting region is known. All of these factors must be taken into consideration when determining how well an evacuation model predicts the assembly exercise. These factors and how they are addressed are described and discussed in the paper.

Finally, the results from blind simulations using maritimeEXODUS for this assembly exercise are presented and compared with the measured data. A number of measures are proposed to assess the goodness of fit between the predicted model data and the measured data, including those presented in [5]. In addition, a methodology is proposed for running validation simulations using this data set which includes a set of appropriate acceptance criteria. It is proposed that these protocols could be used by IMO as part of a validation suite to determine acceptability of maritime evacuation models.

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REFERENCES

[1] IMO, "Interim Guidelines for Evacuation Analyses for New and Existing Passenger Ships", IMO MSC/Circ 1033, 6 June 2002

[2] IMO MSC Circ 1238, 2007

[3] FP 51/WP.3, 8 Feb 2007

[4] Galea, E.R., Brown, R.C., Filippidis, L., and Deere, S., "Collection of Evacuation Data for Large Passenger Vessels at Sea", *Pedestrian and Evacuation Dynamics 2010. 5th International Conference. Proceedings. March 8-10, 2010, Springer, New York, NY, Peacock, R.D., Kuligowski, E.D., and Averill, J.D., Editor(s), pp 163-172, 2011*

[5] Peacock, R.D., Reneke, P.A., Davis, W.D., Jones, W.W., "Quantifying Fire Model Evaluation Using Functional Analysis, *Fire Safety Journal*, 22 (1999), pp167-184

Influence of emissions on pedestrian evacuation

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INTRODUCTION

We have developed a pedestrian simulation, which is capable of integrating an emission model that influences the movement of occupants. Two alternatives, online and offline coupling have been implemented. Offline coupling can be employed to integrate data generated by accurate, but time-consuming methods, like NIST FDS (Fire Dynamics Simulator developed by the National Institute of Standards and Technology). The distribution of substances is calculated by a NIST FDS and afterwards the results are synchronized with the downstream pedestrian simulation (in contrast to direct coupling [1]). For online coupling the emission is not pre-calculated by a standalone model, but directly integrated into the main loop of the pedestrian simulation. Therefore, an immediate interaction between occupants and the effects of a certain emission is feasible. In addition, the applied algorithms are optimized for performance, while still providing acceptable accuracy. This feature is essential for online egress planning as demanded by fire alarm systems: both fire spread and pedestrian motion can be simulated faster than real-time. In case of a fire, the simulation calculates situational, individual egress routes for each occupant (or each group of occupants). Using super-real-time calculation, the updated egress route can be communicated to the occupants immediately.

MATERIALS AND METHODS

For accurate offline simulation, fire and egress computations are performed separately and sequentially. First, the propagation of a fire is simulated by a dedicated fire model (we have integrated NIST FDS, which is based on computational fluid / gas dynamics: CFD). Afterwards the result of the fire simulation is piped into a model for pedestrian simulation. The temporal distribution of the fire is modeled by potential fields, repelling pedestrians. However, since the distribution of the fire is computed separately, an interaction between the pedestrians and the fire can hardly be modelled. Therefore, we additionally provide online coupling of fire and egress simulation, i.e. after each time step of the fire simulation the pedestrian simulation is updated and vice versa. Due to the computational complexity of models based on CDF, those approaches cannot be performed in real-time, which however is a strict requirement for incorporating the simulation into a fire alarm system. Real-time simulation is a must for time critical applications like voice evacuation and dynamic egress routes: an optimal egress plan is calculated by a simulation and communicated to the occupants online. In addition, the high accuracy of a fire model based on computational fluid dynamics is not necessarily required for the controller of such a fire alarm system. Therefore we have developed a separate module for online fire simulation (see below).

Since we have chosen a cellular automaton for the movements of pedestrians, our approach of integrating a fire simulation (offline and online) is also based on this model. The examined area is

discretized into hexagonal cells, where each cell can be occupied by one person. If cells are afflicted by the distribution of smoke or fire, those cells will be marked as blockers for the next step in pedestrian simulation. This might contingently result in a recalculation of the best egress path for some pedestrians.

While the fire distribution of the offline coupling is derived from NIST FDS, we have developed a dedicated model for online coupling of emissions (like fire and smoke). An efficient method to couple a continuous model with a discretized simulation environment is constituted by the so-called Eikonal equation. The Eikonal equation is used to calculate the arrival time of waves, which are propagated by a certain speed. The speed of wave propagation is not limited to a constant value, but can take any function depending on the position in the simulation area. Possible implementations comprise a dependency of the wave propagation on material parameters, or on external parameters like the wind speed, or on elevation profiles or whatever might influence the distribution of a fire.

Apart from the advantages mentioned above, it is also possible to couple a simulation with more than one Eikonal equation, for example if different models for the propagation of fire and smoke are required. Furthermore, obstacles can be included into the simulation by simply setting the speed of wave propagation to zero inside these areas.

Although the simulation based on an Eikonal equation is a continuous method, the numerical solution of the equation is subject to a certain discretization on a computer. However, a fine discretization can be chosen, since efficient methods are provided to solve Eikonal equations (e.g. the so-called Fast Marching Method [2], an algorithm which solves the Eikonal equation in $O(n \log(n))$ steps, where n is the number of points in the discretization). Given these prerequisites, the distribution of fire and smoke (and other harmful substances) can be coupled to a real-time pedestrian simulation. In addition, those simulation models provide an accuracy sufficient for online evacuation applications. However, the high accuracy of fine-gridded CFD-based models like NIST FDS cannot be reached, i.e. the offline mode is still the favorable option for detailed planning purposes.

EXAMPLES

In one example we have simulated the spread of toxic substances (like smoke) in the entrance area of a subway station. There are two alternative egress paths (passageways leading from the subway exit to the main escalator / exit stair). Once the toxic substance spreads, the shortest egress path is eventually blocked after a given time. Therefore, the pedestrians are forced to take an alternative egress path, which is longer but not affected by toxic substances. This kind of simulation can be employed to test the layout of egress ways under extraordinary events (like fire and smoke emission).

A second example assesses the evacuation of occupants from a multi-storey building. The goal of the simulation is finding an optimum egress route for each of the occupants (i.e. the simulation calculates the optimum egress route for each individual person). The optimum egress route might differ from person to person, since the occupants are located in different parts of the building with different accessibility of the exits. This kind of simulation could be directly linked to an intelligent fire alarming system, which advises each individual occupant how to exit the building in case of an emergency. Possible channels of notification are, for example, sending a short message on the mobile, displaying the exit route on the individual desktop, or using voice evacuation etc. In order to calculate such detailed plans, the simulation needs to gather as much information as possible about the environment. Therefore, regarding this example, the fire alarming system has to be connected to a variety of sensors, like occupancy detection (e.g. cameras, sensitive floor plates) or fire / smoke detection.

REFERENCES

- [1] Korhonen, T. and Hostikka, S. (2009). *Fire Dynamics Simulator with Evacuation: FDS+Evac. Technical Reference and User's Guide*. VTT Technical Research Centre of Finland.
- [2] Sethian J. (1999). *Level Set Methods and Fast Marching Methods*. Cambridge University Press.

RiMEA - A way to define a standard for evacuation calculations

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Since many years the RiMEA-Richtlinie (Richtlinie für Mikroskopische Evakuierungs Analysen - Guideline for Microscopic Evacuation Analyses; RiMEA-Guideline) is a guideline for German-speaking authorities to check evacuation analyses of complex buildings. Based on the RiMEA-Guideline expert reports are written to ensure that the fundamental questions of an evacuation analysis are answered.

Since November 22nd, 2011, a German DIN Specification (like a Pre-Standard) for evacuation calculations (DIN Spec 91284) is available. This DIN Specification is based on the RiMEA-Guideline and was developed together with the RiMEA society (RiMEA e.V.). The first part of this presentation will show how this DIN Specification (DIN Spec 91284) was developed and what kind of requirements have to be fulfilled to “transform” the RiMEA-Guideline to this German DIN Specification. Additionally we will show what are the differences between this DIN Specification and the RiMEA-Guideline.

In an Annex the RiMEA-Guideline presents a set of test cases for microscopic software tools for evacuation calculation. This will be the second part of the presentation. These test cases should be used by the software developer to show results of the software by themselves, and to present results in a written report to e. g. local authorities for validation of the model used in the software and verification of its correct implementation.

These test cases are very basic, to ensure that any suitable software is able to run the test scenarios. The goal of these test cases is to show users of software tools the differences or equity of different software tools, furthermore these test cases should show local authorities that the software tools which have been used for an evacuation report fulfill at least this minimum standard for software tools. At the moment (November 2011) the RiMEA-Guideline consists of 14 test cases for software tools. These test cases are combined to different groups of verification and validation test cases, thus we have

- Test cases for different software components (test case 1 – 7)
- Functional verification/validation (test case 8)
- Qualitative verification/validation (test case 9 - 14)

In the following we present a short overview about these test cases:

- Test case 1: Keep velocity in a floor
- Test case 2: Keep velocity upstairs
- Test case 3: Keep velocity downstairs
- Test case 4: Specific flow through an opening

- Test case 5: Response time
- Test case 6: Moving around a corner
- Test case 7: Assignment of demographic parameter
- Test case 8: Parameter study
- Test case 9: Evacuation of a large room
- Test case 10: Assignment of evacuation routes
- Test case 11: Choosing an evacuation route
- Test case 12: Effects based on bottlenecks
- Test case 13: Congestion in front of stairs
- Test case 14: Route choice

In this part of the presentation we will show results of different software tools based on the test cases, which are part of the RiMEA-Guideline. The goal of this part of the presentation is also to assure developers of international non-German software tools to use this kind of verification/validation suite to show the capabilities of their software tools. Furthermore we would like to invite everybody to submit new test cases for the RiMEA-Guideline, thus the number of test cases will increase, thus at the end a wide and well accepted „benchmark suite“ can be presented to users of software tools for evacuation calculation and to local authorities, which have to accept results which are calculated by these software tools.

In the last part of the presentation we will show how the RiMEA guideline was developed over several years. Therefore we will give an historical overview about the development of the RiMEA guideline, which was first presented at PED 2005 in Vienna to an international audience. Based on the first version of the RiMEA-Guideline (January 2004) and the actual edition, which will be adopted at the RiMEA member meeting in March 2012 we will show how the guideline grows (18 pages 2004, actually 32 pages 2011) and what changes have been done. We furthermore want to show how a new version of the RiMEA-Guideline is developed and what are the further plans of RiMEA e. V., the society which is responsible for this Guideline.

Fuzzy prediction of pedestrian steering behaviour with local environmental effects

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ABSTRACT

This research focuses on prediction of pedestrian walking paths in indoor public environments during normal and non-panic situations. The aim is to incorporate imprecise and subjective aspects of pedestrian interaction with the environment to enhance steering behaviour modelling. The proposed model introduces a fuzzy logic framework to predict the impact of environmental stimuli, within a pedestrian's field of view, on movement direction. Attractive and repulsive effects of the surrounding environment are quantified by social force method. A high flow corridor in an office area is considered as a case study. Stochastic simulation is used to generate walking trajectories, calculate a dynamic contour map of environmental stimuli in each step and recognise the high flow walkable areas in the corridor.

FUZZY LOGIC STEERING PREDICTION MODEL

Wayfinding behavioural studies have revealed that the spatial ability of pedestrians allows them to find a path from the current location to a destination [1]. During wayfinding activities pedestrians are confronted with environmental stimulations that change dynamically after each step. Environmental stimulations have important influence on visually directed walking tasks. However, variable factors such as trip intention and pedestrian's attributes are contributing elements that make the prediction of pedestrian–environment interactions an imprecise and fuzzy problem.

Dynamical changes of environmental stimulations constantly update the pedestrians' world view of their surroundings and affect their perception. Understanding a pedestrian's perception of environmental stimuli is necessary to accurately estimate the pedestrian movement [2]. It is believed that information exchange within a dynamic environment contributes to the control of human locomotion tasks [3]. Golledge et al. [4] elevated the question of information integration of the route attributes. They highlighted that orientation and movement direction are more fuzzy and related to a wide range of elements. Recently, fuzzy rule-based systems have also been successfully applied in the field of robot navigation and path planning [5]. Fuzzy logic has the capability to model the imprecise and diverse nature of pedestrian perception and reaction towards the environmental impacts.

This study highlights two challenging issues: firstly, it addresses how to quantify the environmental effects, and secondly, how the environmental stimuli influence the spatial behaviour. In this context, we have proposed a fuzzy logic approach to model the local steering behaviour. The fuzzy system comprises of three inputs, one output and 216 rules as illustrated in Figure 1. Inputs are the agent's perception from three possible future travel points, which are described as {Front Position, Right Position, Left Position}. The summation of attractive and repulsive stimulation is assessed for each

future position. This perceived information is then recognised as {High attractive, Medium attractive, Low attractive, Low repulsive, Medium repulsive, High repulsive} to express level of perception. Therefore, each input consists of six membership functions and change of movement direction can be inferred by the output of fuzzy system.

To succinctly express pedestrian behaviour, we have made the following five assumptions: (i) all the objects induce attractive or repulsive effects to the surrounding environment, and the cumulative sum of attractive and repulsive stimulations is computed for each point in the terrain surface; (ii) the levels of stimulation in the front, right and left hand side of the agent are the inputs of the fuzzy system; (iii) in each step along the movement path, three alternatives exist (move forward, change direction to the right or to the left); (iv) the agent is able to change the direction between a continuous range from, -12 to +12 degrees, in subsequent steps; and (v) the angular change of direction is the final command for movement driven from fuzzy rules.

The three fundamental elements of the model investigated are psycho-sociological motivations, dynamic environmental information that is provided by objects located in the field of view to reflect local awareness, and the movement direction that is the output of fuzzy logic system.

Simulation of fuzzy steering model with local environmental effects

Contradictory psycho-sociological forces motivate the agent to move towards a desired destination. The Helbing social force model is one of the more practical and reliable methods describing the behaviour of pedestrians, which considers the effects of attractive and repulsive forces [6]. We have adopted this approach to quantify the environmental influences. Figure 2 shows the trace of walking paths in the simulated corridor and the potential attractive, repulsive and total stimulation in that area due to the printer and the exit door. It is assumed that the printer has both attractive and repulsive effects, while the exit door provides an attractive influence. Further simulations have been completed to gain a better understanding of algorithm performance and the impact of dynamic changes of environmental stimuli.

CONCLUSION

The simulation results indicate that the proposed fuzzy-based approach is a promising method to model the pedestrian walking path under normal conditions. In this methodology, the individual-based representation of terrain employs the concept of field of view to capture visual stimuli that impact walking direction and acquire dynamic environmental information, which is a necessary characteristic for local awareness.

To verify the concept, a two dimensional space with walls, printer, entrance and exit was studied. As pedestrian interaction with the environment is an important feature of steering behaviour, we assessed the level of induced effects exerted by the environment on the pedestrian employing social force model to obtain the turning angle of direction for the next step using fuzzy logic framework. In this regard, fuzzy logic offers a framework to model the problem considering both imprecise nature of environmental effects and diversity in pedestrian perception and decision making.

REFERENCES

[1] D. Gibson, *The Wayfinding Handbook: Information Design for Public Places.*, first ed. New York: Princeton Architectural Press, 2009.

[2] J. D. Wineman and J. Peponis, „Constructing spatial meaning: Spatial affordances in museum design,“ *Environment and Behavior*, vol. 42(1), pp. 86-109, 2010.

- [3] B. R. Fajen and W. H. Warren, „Behavioral dynamics of steering, obstacle avoidance, and route selection,“ *Journal of Experimental Psychology: Human Perception and Performance*, vol. 29(2), pp. 343-362, 2003.
- [4] R. G. Golledge, A. J. Ruggles, J. W. Pellegrino, and N. D. Gale, „Integrating route knowledge in an unfamiliar neighborhood: Along and across route experiments,“ *Journal of Environmental Psychology*, vol. 13(4), pp. 293-307, 1993.
- [5] H. Seraji and A. Howard, „Behavior-based robot navigation on challenging terrain: A fuzzy logic approach,“ *IEEE Transactions on Robotics and Automation*, vol. 18(3), pp. 308-321, 2002.
- [6] D. Helbing, I. Farkas, and T. Vicsek, „Simulating dynamical features of escape panic,“ *Nature*, vol. 407(6803), pp. 487-490, 2000.

Fundamental diagram as a model input – direct movement equation of pedestrian dynamics

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Leading by advantages of continuous and discrete approaches to model pedestrian dynamics we develop a new discrete-continuous model SIGMA.DC [5]. In this model people (particles) move in a continuous space in this sense model is continuous, but number of directions where particles may move is a model parameter (limited and predetermined by a user) in this sense model is discrete. Here we deal with an individual approach when models give coordinates of each person.

A space and an infrastructure (obstacles) are known. People may move to free space only. Shape of each particle is a disk with a diameter of d_i , [m], initial position of a particle i is given by the coordinate of the center of the disk $x_i(0) = (x_{i1}(0), x_{i2}(0))$, $i=1, \dots, N$, N – number of particles. Each particle is assigned with a free movement velocity v_{i0} , [m/s], square of projection, mobility group, age of each person. Let assume the nearest exit as a target point of each pedestrian. Intersections of particles, particles and obstacles are forbidden. To orient in the space particles use the static floor field S [8].

An idea of the approach proposed is come from the formula that connects path and velocity. It's finite-difference expression in a vector way gives as an opportunity to present movement equation in a direct form, when current position of the particle is determined as a function of a previous position and local particle's velocity. For each time t coordinate of each particle i are given by the following formula:

$$x_i(t) = x_i(t-dt) + v_i(t)e_i(t)dt, i=1, \dots, N, \quad (1)$$

where $x_i(t-dt)$, [m, m] – coordinates in previous time moment; $v_i(t)$, [m/s] – current velocity of the particle; dt , [s] – length of a time step (fixed).

Unknown values in (1) are the direction $e_i(t)$ and the shift $v_i(t)dt$. The direction is proposed to be random. Each time step t each particle i may move in one of the q predetermined direction, q – number of directions, model parameter. Choice of the direction where particles make a next step is stochastic and based on probabilities distribution. "Right" probabilities vary dynamically and are given by balancing of three contributions: a) the main driven force (given by destination point), b) interaction with other pedestrians, c) interaction with an infrastructure (non movable obstacles). Procedure of calculating probabilities to move to each of the directions is adopted from previously presented stochastic Cellular Automata (CA) floor field (FF) model [2, 3, 4, 6] and gives the highest probability to direction that has most preferable conditions for movement considering other particles and obstacles and strategy of the people movement (the shortest path and/or the shortest time). Directed movement is given by using the static floor field that shows a distance from each point of the space to the nearest exit.

At each time step current velocity $v_i(t)$ of the particle is determined by local density in accordance with the fundamental diagram [1, 7]. To be more exactly we use analytical expressions of velocity versus density that is given by formula in [1]. This formula was derived from previously presented results in the book by Predtechenskii and Milinskii [7]. Obviously one can use other data, (velocity vs. density) that is in table or formula form.

In the class of continuous model such approach has an advantage. Usually differential equation is used to give movement equation of the particle. To simulate movement of N particles a system of differential equations are solved. It worse to be mentioned that numerical solution of the problem in such statement is “a hard nut to crack”. Forces that act to the particle could not be adopted from physical laws directly and should satisfy at least one quality condition: model flow should correspond fundamental diagram. To describe forces in such way is difficult problem.

In the approach proposed we leaved apart this step. The movement equation is given in direct form, and velocity is controlled by local density in the direct form. In an assumption that movement direction is “right” such approach should give strong coincidence of the model flow and experimental flow that is used. So the success in the pedestrian movement modeling using such approach is to choose “right” directions for each particle in each time step. Approach of choosing directions that was created for CA model was adopted and adapted for continuous space.

Model dynamics was investigated for simple geometry, straight corridor $b=2$ meters in width. For periodic boundary conditions there was a control line and we measured time T that $N=1000$ people needed to pass this line. There was observed a perfect coincidence of the model flow $J=1000/T/b$, [pers/s/m], and real data [1] for low and middle densities. For high densities model is considerably slower than a real flow. It seems to be a computational impact of the model. The fact is the lower free movement velocity [1, 1] the better coincidence of the flows observed for high densities. Experiments on open boundary conditions showed a typical and qualitatively the same behavior that model should reproduce, and RIMEA collection presents. Experiments on other geometries and further development of the model are going on.

REFERENCES

- [1] Kholshchevnikov, V.V., Samoshin, D.A. (2009) *Evacuation and human behavior in fire*, Moscow, Academy of State Fire Service, EMERCOM of Russia, 212 p. (Rus.)
- [2] Kirik, E., Yurgel'yan, T., Krouglov, D. *Artificial Intelligence of Virtual People in CA FF Pedestrian Dynamics Model // LNCS*, V. 6068, 2010.– pp.513-520.
- [3] E. Kirik, T. Yurgel'yan, D. Krouglov. *On Influencing of a Space Geometry on Dynamics of Some CA Pedestrian Movement Model // Lecture Notes in Computer Science*, V. 6350, *Cellular Automata*, 2010. – P. 474-479.
- [4] E. Kirik, T. Yurgel'yan, D. Krouglov. *On Time Scaling and Validation of a Stochastic CA Pedestrian Dynamics Model // In the book “Pedestrian and Evacuation Dynamics”, editors Richard D. Peacock, Erica D. Kuligowski, Jason D. Averill, 2011, 819-822 (DOI: 10.1007/978-1-4419-9725-8_80).*

[5] Kirik, E., T. Yurgel'yan, A. Malyshev. *On discrete-continuous stochastic floor field pedestrian dynamics model SIGMA.DC // In the book "Emergency evacuation of people from buildings", 2011. – pp. 155-161.*

[6] Kirik, E., Yurgel'yan, T., Krouglov, D. (2011) *On realizing the shortest time strategy in a CA FF pedestrian dynamics model // Cybernetics and Systems, vol.42:01, 1-15.*

[7] Predtechenskii, V.M., Milinskii, A.I. (1978) *Planing for foot traffic flow in buildings. American Publishing, New Dehli. Translation of: Proektirovanie Zhdanii s Uchetom organizatsii Dvizheniya Lyudskikh potokov, Stroiizdat Publisher, Moscow, 1969.*

[8] Schadschneider, A., A. Seyfried. *Validation of CA models of pedestrian dynamics with fundamental diagrams // Cybernetics and Systems, Vol. 40 (5), 2009, 367–389.*

Experimental study and modelisation of pedestrian space occupation and motion pattern in a real world environment

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The purpose of this work is to study the behaviour of pedestrians in a real world environment with a very simple geometry. Ideally, we would like to study a long, uniform corridor which is used just as a transition place, i.e. it has no lateral exits or entries, shops or other points of interest. Furthermore, the corridor should not present any narrowing or widening, nor any architectural elements or equipments that can influence the way pedestrians use the space, and all the pedestrians in the area should behave as commuters (no gatherings and the like). Such an environment is expected to be symmetrical along the direction of the corridor, and we want to study how the pedestrian density, velocity and flux change as a function of the distance from one of the corridor's walls (i.e. in the direction orthogonal to the corridor axis).

As an approximation to this ideal environment we decided to study an underground area in Umeda (Osaka) where some corridors connect a shopping area with a railway station. These corridors are quite uniform, without any shop, and used almost only by people transiting between the station and the shopping area, and thus their structure is quite similar to the ideal one. The pedestrian positions were recorded in two working day afternoons using 2D laser range finders, a technology that allows for automatic detection with an error of order 5 centimetres [1]. This technology suffers of cluttering problems when the density gets very high but works very well at the densities occurring in these corridors.

We divide the environment in 2 dimensional square cells of linear size 250 mm and define on each of them 5 observables, namely: the pedestrian density ρ as the number of pedestrians recorded in the cell divided by the number of observation time instants and cell area; average vectorial velocity; average speed; current j defined as the product of ρ and average vectorial velocity; and flow ϕ defined as the product of ρ and average speed. Analysing these quantities we are able to spot and clip the areas of the environment that better satisfy our requirements for a uniform corridor, and then further filter the data to exclude from our statistical analysis those pedestrians that are not moving along the corridor's axis (this filtering process is valid provided that the amount of excluded data is negligible with respect to the total amount of data in the clipped area). The filtered data are then integrated on the (symmetrical) corridor direction in order to obtain 1D distributions.

We find that the j distribution has two extrema since the flux of pedestrians in the corridor splits in two according to the walking direction (people walk on the left side of the corridor according to the Japanese traffic convention), with the two fluxes assuming clearly separated maxima. Nevertheless, at least in the studied density regime, the two fluxes overlap resulting in an almost constant ϕ distribution between the two j maxima. The ϕ distribution drops to zero close to the walls. The

rho distribution is very similar to the phi one, suggesting an almost flat distribution for the speed. Accordingly, we find that the speed distribution is a convex function assuming a maximum in the centre of the corridor and minima close to the walls, but the difference between the maximum and the minima is no bigger than 10 per cent. Interestingly, even if we study the speed distribution for the individual fluxes, we find the maximum to be at the centre of the corridor, i.e. on the right of the the j maximum, suggesting a tendency to overcome on the right.

We propose a theoretical model to explain the distribution of pedestrians in a given flux. Denoting with x the distance of the pedestrian from one of the walls we introduce an “energy function” (actually a comfort function) $E(x)$ that has diverging terms on the walls and is quadratic in the distance from a given point c (the point where the pedestrian attains minimum “energy” i.e. maximum comfort). Assuming, following the principles of statistical mechanics, that the probability distribution of pedestrians is given by a Boltzmann factor, $p(x)=\exp(-E(x))$, we find results in good agreement with the rho distribution in our data, provided that the quadratic term in the energy is limited to a bounded value to explain the finite probability of walking on the “wrong” side of the corridor. Calibration on real data quantitatively shows that c is always clearly located in the left side of the corridor. The energy function could be extended in the (x,v) space to account also for the velocity distribution, which can be described quite well by a Gaussian function (even if the mode is always slightly higher than the mean; the distribution cannot obviously be described as Maxwell-Boltzmann, since velocity has a clearly defined direction); if analysed for different positions in the corridor, the mean value of the Gaussian velocity distribution assumes a maximum value at the centre of the corridor, and is, for each flux, biased toward the right, suggesting once again a tendency to overtake on the right.

It was suggested [2] that the tendency to walk on a given side of a corridor can be related to a (culturally dependent) bias in collision avoiding. With simulations based on different microscopic pedestrian models [3,4] we verify if this assumption is in agreement with our empirical findings and statistical model. Furthermore we investigate which kind of modifications have to be introduced in the models to account for the observed velocity distribution, and we investigate which are the effects of these modifications on simulation of systems at different densities.

REFERENCES

- [1] D.F. Glas, T. Miyashita, H. Ishiguro, N. Hagita, “Laser-Based Tracking of Human Position and Orientation Using Parametric Shape Modeling”, *Advanced Robotics*, 23 (4), 405-428 (2009)
- [2] M. Moussaïd, D. Helbing, S. Garnier, A. Johansson, M. Combe and G. Theraulaz, “Experimental study of the behavioural mechanisms underlying self-organization in human crowds”, *Proceedings of the Royal Society B: Biological Sciences*, 276, 1668, 2755-2762, (2009)
- [3] A. Johansson, D. Helbing, P. S. Shukla (2007), “Specification of the social force pedestrian model by evolutionary adjustment to video tracking data”, *Advances in Complex Systems*, 10, 271-288.
- [4] F. Zanlungo, T. Ikeda and T. Kanda, “Social Force Model with explicit collision prediction”, *Europhysics Letters*, 93, 68005 (2011).

Psychological aspects of german signal words in evacuation warnings

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Warnings play an important role in evacuation. They aim at avoiding or reducing injury and loss of life (Wogalter & Laughery, 2006). The recipients must be able to act according to the warning which implies understanding the meaning, knowing what to do (leave the site) and doing it. But often, the meaning of a warning is not clear or it cannot be properly understood. This problem of poorly designed warnings has been addressed for some time. As already reported in Sime (1995), during an unannounced evacuation exercise in an underground station in Great Britain, the warning given was very imprecise and did not contain specific instructions. Passengers gathered information instead of leaving the station immediately. In case of lack of information or unclear meaning, people will spend time for collecting information instead of leaving the site (Tubbs & Meacham, 2007). Thus, the time before evacuation starts could be shortened significantly by early and precisely given instructions included in warnings.

It is essential for safety to provide adequate information about the danger at hand. In some situations, situational cues such as smoke, heat or noise serve as warning signals. Yet, people that are potentially affected might detect them too late in order to recede safely. In many cases, explicit warning signals are even the only source of information for the persons concerned (Edworthy & Adams, 1996).

Warnings therefore have an alerting function and an informing function regarding the source and consequences of danger as well as the necessary action (Wogalter & Laughery, 2006). An important part of visual and verbal evacuation warnings are signal words such as “attention”, “warning”, “notice”. They alert attention while transporting information as well (Edworthy & Adams 1996; Hellier, Aldrich, Wright, Daunt & Edworthy, 2007). But not every signal word used in natural language is appropriate for every message. The response to the warning will partly depend on the connotations or semantic field of the words used. Explicitness is important, as well as perceived urgency. When designing a warning, psycho-acoustic urgency of the signal word used should match the contextual urgency (urgency mapping, e.g. Edworthy et. al, 2003). In that way, recipients intuitively understand the danger at hand, react more quickly and show more compliance with the message (Laughery et al., 1993).

For English signal words, the semantic field has been researched for at least two decades (e.g., Edworthy et al., 2003 Hellier et al., 2007; Wogalter & Laughery, 2006). Relevant dimensions are perceived hazard, arousal strength, intended carefulness, and perceived urgency. For example, independent of modality, “note”, “notice”, “attention” seem to convey less danger and urgency than “danger” or “warning” (Edworthy et al., 2003). For German signal words, no studies were found. So, for the design of effective evacuation warnings (loud speaker announcements/ public announcements), a study on signal words using two experiments was conducted. The aim of the study is the mapping of German signal words

on the dimensions of perceived urgency and explicitness. In first tests the authors had found that the meaning of the signal words varied with context. In consequence, a specific context of loud speaker announcement in underground stations was chosen because the results of the study are to be used in the research project OrGaMIRPLUS. This project, funded by the German Ministry of Education and Research, deals with aspects of human factors in evacuation of underground transportation systems.

In two experiments, the perceived urgency and explicitness of visually presented signal words was analysed. We chose signal words which are similar to those already used in English studies and standards and which can be found in German warnings as well („Achtung“ - attention, „Gefahr“ - danger, „Hinweis“ - notice, „Vorsicht“ – beware /be careful, and „Warnung“ – warning). In Experiment 1 (n=51), the signal words were presented as written text. Subjects answered eight questions using standardized ratings scales regarding the five signal words. Subjects were instructed to imagine they were waiting for the train when an announcement started. In Experiment 2 (n=36, none of them participated in experiment 1), the signal words were presented in spoken language (recordings by a professional female announcer). Subjects listened to the signal words and to announcements beginning with signal words and then answered the same questions using ratings.

We expected to find a clear ranking order between five signal words while the ranking order for urgency should be the same as for explicitness. For Experiment 1, data showed that “Gefahr” (danger) is perceived as most urgent and most explicit while “Hinweis (notice) is least urgent and least explicit. But for the other three signal words, no clear order could be found. Ranking orders for explicitness and urgency were the same. Results for experiment 2 are still being analysed. These findings have a direct relevance for evacuation warnings because “Achtung” (attention), “Warnung” (warning) and “Vorsicht” (beware /be careful) are most often used in warnings, also in underground loud speaker announcements. Those responsible for evacuation rely on signal words that convey quite varying meanings to the listeners.

REFERENCES

- Edworthy, J. and Adams, A. (1996). *Warning design: A research prospective*. Oxford: Taylor & Francis.
- Edworthy, J., Hellier, E., Walters, K., Clift-Mathews, W. & Crowther, M. (2003). *Acoustic, semantic and phonetic influences in spoken warning signal words*. *Applied cognitive psychology*, 17, 915-933.
- Hellier, E., Aldrich, K., Wright, D. B., Daunt, D. and Edworthy, J. (2007). *A multi dimensional analysis of warning signal words*. *Journal of risk research*, 10 (3), 323-338.
- Parsons, S. O., Seminara, J. L. and Wogalter, M. S. (1999). *A summary of warning signal research*. *Ergonomics in design*, 7 (1), 21-31.
- Sime, J. D. (1995). *Crowd psychology and engineering*. *Safety Science*, 21(1), 1-14.
- Tubbs, J. S. and Meacham, B. J. (2007). *Egress design solutions: A guide to evacuation and crowd management planning*. Hoboken: John Wiley and Sons.
- Wogalter, M. S. and Laughery, K. R. (2006). *Warnings and hazard communications*. G. Salvendy (Hrsg.), *Handbook of human factors and ergonomics (3rd ed., S. 889-911)*. Hoboken: John Wiley and Sons.

Effect of guidance information and human relations among agents on crowd evacuation behavior

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INTRODUCTION

Evacuation of people in times of emergency or disaster is a complex task. It is difficult to conduct physical experiments that involve many humans and real environments, or to make effective plans for predictable situations based on the data of past disasters. Disaster simulation systems have been employed to make the prevention plans for the disasters and to check the plans. In simulation systems, evacuees have been treated equally, or the difference in age and sex of the evacuees have been involved as the parameters of simulations [1].

An agent based crowd evacuation simulation is proposed in this paper, to simulate evacuation behaviors that contain following phenomena. The phenomena were reported to occur in evacuations [2].

1. Rescue workers who enter into a building move in the opposite direction of evacuees who go out of buildings. The movement causes interactions in the evacuations. Family-minded human behaviors such as parents seek for their children, may also cause similar interaction in crowd evacuation.
2. Evacuation guidance leads people to evacuate safely and efficiently. While some people start to evacuate immediately when they hear the evacuation guidance, others may continue doing works if the guidance is not clearly announced. The other may not hear the guidance at the worst case.

FEATURES OF OUR SYSTEM AND EVACUATION SCENARIOS

We propose a system that simulates the evacuation behavior of crowd with the phenomena by considering human relation among agents and guidance announcement at emergencies. Features of the system are followings:

1. In emergencies, human behaves differently than usually. The behaviors are affected by people's mental condition. BDI (Belief-Desire-Intention) model is employed to present how agents select the actions according to the situations at sense-reason-act cycle.
2. Parents take care of their children. Their altruism force that comes from his/her own human relations is added to a social force in Helbing's model [3]. It works when a parent waits till his or her child catches up, for example. This may become blockades to others who hurry to refuges.
3. In disasters, an evacuation route may be rendered impassable by rubble. The evacuees exchange information on the dynamically changing situations among them. Two types of information propagations are introduced; communication between a security officer and an evacuee, and communication among evacuees.

Following three scenarios are presented to show our features that traditional evacuation systems have not had.

Scenario 1. Pairs of parent-child evacuation from campus:

An event is held at a campus that consists of two buildings. Many pairs of parent-child participate the event, and they are divided into two groups. When disasters occur, they are supposed to evacuate from buildings to a nearby refuge. Following three cases are simulated and results show different evacuation behaviors although there is the same number of agents in each building.

- a) Parents and their children are in the same building.
- b) Agents are randomly located so that some parents and their children are in different buildings.
- c) For all parent-child pairs, parents and their children are in different buildings.

Scenario 2. Evacuation with guidance from security office:

In an emergency, people go to the nearest refuge. When fire occurs near one of refuges, a security agent announces that it is safer to go other refuges than the refuge near the fire. Some agents follow the guidance, while other agents do not. In some simulations, there are phenomena that some agents that don't follow the guidance are involved in the movements of a number of people. Their motions that go to the different refuge is opposite to the others' movements and cause traffic jams.

Scenario 3. Evacuation guidance and communication among civilians:

During the evacuation from a building, occupants exchange information on disasters. According to the information, some occupants change their actions according to their knowledge on emergency stairs in the building. The changes of action affect the evacuation time from the building. Simulation results show better quality of guidance makes evacuation time shorter.

SUMMARY AND DISCUSSION

Recently, people have been keen to assess the safety of society after several disasters, and analysis of evacuation behavior has received increased attention. The agent-based simulation provides a platform for computing individual and collective behaviors in crowds.

We present two ideas; an agent behavior model presented with BDI and information propagation through communication, to generate the phenomena observed in crowd evacuations. The BDI model presents the human relations among agents and patterns of its own behaviors. The communication enables to represent how much agent trust the information that they get through communication among agents. The simulation results of the evacuation scenarios reveal the followings:

- 1) Property of human relations and information in the guidance affect evacuation behaviors. The behaviors are different from ones of the rest people.
- 2) The behaviors of some agents affect the evacuation behaviors in all. It causes congestion and it takes more time to evacuate as in real life.

These results demonstrate that our model provides an effective simulating method of crowd behavior in emergency situations, and that check the evacuation plans and the announcement of guidance.

REFERENCES

[1] G. Santos and B. E. Aguirre: *A Critical Review of Emergency Evacuation Simulation Models*, NIST Workshop on Building Occupant Movement during Fire Emergencies, 25-50, June 9-10, 2004.

[2] J.D.Averill: *NIST nstar 1-7: Occupant behavior, egress, and emergency communication*, Sep. 2005.

[3] D.Helbing, et. al: *Simulating dynamical features of escape panic*, NATURE, 487-490, Sep. 2000.

Using the social force model to represent the behavior of pedestrians at chaotic intersections of developing countries: the case of Peru

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INTRODUCTION

In the cities of Peru an important set of intersections present problems of congestion, pollution and mainly accidents. The study by [1] indicates that among 178 countries considered, Peru is the first in pedestrian deaths from road accidents (78%). Many of these problems are generated because the traditional management system gives priority to traffic instead of vulnerable users (pedestrians, the disabled, cyclists, etc.). Peruvian politicians privilege to motor vehicles and think that any improvement for the other user groups would imply loss of capacity on the roads and more travel time and delays for vehicles.

Due to mismanagement and the characteristics of Peruvians pedestrians and drivers, there are several conflicts between pedestrians, cyclists and vehicles that can not be represented by traditional traffic modeling tools. Studies in some cities of Peru [2] indicate that analytical models would not be adequate to analyze traffic situations close to congestion or where aggressive driving and multiple points of conflict between the modes are present.

In order to assess accurately the benefits of applying mitigation actions is necessary to use together a road safety procedure with traffic and pedestrian microsimulation model that can be able of representing the behavior of Peruvian pedestrians and its interaction with other transport modes [3] Traditionally, the behavior of pedestrians has been modeled as if they were gases [4-5] and fluid [6,7,8] and pedestrian areas have been analyzed in normal traffic conditions and evacuation. In this particular case Pedestrians move governed mainly looking for the safest and fastest route, which is not necessarily through the crosswalk. Therefore we analyze a situation in normal traffic conditions, including random routes and where within the space of the intersection (roads) are conflicts between pedestrians and vehicles. For this reason it is thought that the social force model [9] may represent this chaotic behavior.

OBJECTIVES

The aim of this study is to investigate whether the social force model would be able to represent the chaotic movement of pedestrians at an intersection and the conflicts that occur with other modes of transport. In addition, it seeks to determine whether the mitigation measures would adversely affect vehicular traffic as Peruvian politicians think.

METHODOLOGY

The methodology was to evaluate a signalized intersection in the city of Chiclayo (north of Peru) with a high percentage of vulnerable road users (especially pedestrians who take any route and move among

vehicles). We used the traffic microsimulation software VISSIM and its pedestrian module (based on the social force model).

The data for model construction, calibration and validation were collected during two working days from 11:00 am to 2:00 pm, by manual countings and films, and the peak hour of each day was modeled. The traffic calibration and validation was performed with traffic volumes and queue lengths at the entrances. For this, the parameters of the car following Wiedemann model were adjusted. Also, the volumes of pedestrians and their routes from the simulation matched the field measurements. Twenty five runs were performed for each set of parameters until there was no evidence of difference between the field measured values and the average ones obtained with the simulation. The confidence level was 95%.

The current scenario, calibrated and validated, that shows conflicts among pedestrians, vehicles, people in wheelchair and disabled, was compared with the alternative scenario (with mitigation measures). Among the mitigation measures we can find changes in the number of traffic light phases, sidewalks and crosswalks wider, also the construction of ramps that allow the movement of people in wheelchairs, etc. The proposals focused on providing further facilities for vulnerable road users, improved the public space, and change control devices intersections to improve safety in general.

RESULTS

The results indicate that mitigation measures would allow improve pedestrian's safety and their speed (25% higher). However, not only pedestrian are favored but also traffic circulation. There is a 35% reduction in delays and increased average velocity of 65%.

CONCLUSIONS

The social force model could be used to replicate the behavior of pedestrians and traffic interaction at intersections in Peru. The video generated from the VISSIM software shows the chaotic intersection analyzed and its similarity with the reality. In addition, the results would indicate to authorities that the management measures implemented to improve chaotic environments favor to all users and reduce the possibility of accidents with pedestrians.

REFERENCES

- [1] WHO (2009). *Global status report on road safety. It's time to take action*. World Health Organization. Geneva.
- [2] Cabrera (2010). *¿Can deterministic models and micro simulation analyze properly the signalized intersections in Lima*
- [3] Cabrera, F, Dextre, J. (2010). *Use of check lists and microsimulation to improve road safety of vulnerable users*.
- [4] Helbing (1992). *Complex Syst.* 6, 391
- [5] Helbing (1993). *Stochastische Methoden, nichtlineare Dynamik und quantitative Modelle sozialer Prozesse*

[6] Helbing (1990). *Diplom thesis, Georg-August University, Gottingen, Germany.*

[7] Henderson (1971). *Nature* 229, 381

[8] Henderson (1974). *Transp. Res.* 8, 509

[9] Helbing, D, Molnar P. (1995). *Social Force model or pedestrian dynamics*

Keynote

Wednesday, 6 June - 14.30

Marjolein de Jong, Hasselt University, Hasselt BELGIUM

**The characteristics and needs of pedestrians with mobility impairments:
How to move around comfortably and safely with a reduced ability to walk,
see, hear, feel or process information**

Mobility is one of the preconditions for being able to participate in social life: individuals perform activities because of economic, social, recreational and other personal reasons. Mobility constraints may lead to a decreased participation (World Health Organization, 2001). Making the mobility landscape more inclusive is not an easy task at all: the whole travel chain has to be designed and organized in such a way that the specific needs of several groups are taken into account.

The mobility needs of pedestrians with mobility impairments can be grouped according to three specific barrier contexts: 1) travellers challenged by temporary constraints, 2) active travellers happy to accept some support, and 3) travellers with constant constraints. The accessibility of an environment is not only determined by the barrier context of the person, but also by the environment and the activity undertaken. Depending on these constraints, people with reduced abilities to walk, see, hear, feel or process information can move around more or less independently.

Oral presentations

Wednesday, 6 June - 15.00

- A.7 *Michael Schultz, Technische Universität Dresden, Dresden GERMANY*
Stochastic transition model for pedestrian dynamics
- A.8 *Taku Fujiyama, University College London, London UNITED KINGDOM*
The effects of the design factors of the train-platform interface on pedestrian movements
- A.9 *Dietmar Bauer, AIT Austrian Institute of Technology, Wien AUSTRIA*
Including route choice models into pedestrian movement simulation models
- B.7 *Dirk Hartmann, Siemens AG, München GERMANY*
Dynamic medium scale navigation using dynamic floor fields
- B.8 *Paul Townsend, Crowd Dynamics International, Knutsford UNITED KINGDOM*
Pedestrian gap acceptance in micro-simulation modelling
- B.9 *Frank Huth, Technische Universität Berlin, Berlin GERMANY*
A macroscopic multiple species pedestrian flow model based on heuristics implemented with finite volumes
- C.7 *Mohcine Chraibi, Forschungszentrum Jülich GmbH, Jülich GERMANY*
A simplified force model and enhanced steering for a quantitative description of pedestrian dynamics
- C.8 *Mario Campanella, Delft University of Technology, Delft NETHERLANDS*
Quantitative and qualitative validation for general use of pedestrian models
- C.9 *Naveesh Reddy, PM Dimensions Pvt. Ltd., Gandhinagar INDIA*
FDS+Evac model validation for seated row arrangements

Stochastic transition model for pedestrian dynamics

Michael Schultz, Technische Universität Dresden, Dresden GERMANY

We propose a calibrated two-dimensional cellular automaton model to simulate pedestrian motion behavior. It is a $v\text{-max}=4$ (3) model with exclusion statistics and random shuffled dynamics. The underlying regular grid structure results in a direction-dependent behavior, which has in particular not been considered within previous approaches. We efficiently compensate these grid-caused deficiencies on model level.

The different model approaches for microscopic person dynamics are based on the particular discipline analogies, ranging from hydro-dynamic models to artificial intelligence and multi-agent systems. The complex dynamic human behavior is induced by individual decisions, which are classified to be of short-range (operational) and long-range type (strategic/tactical). The self-organization of persons is a further essential characteristic of human behavior. In contrast to the social force model or the discrete choice model the developed motion model is based on a stochastic approach to handle the unpredictable behavior by individual path deviations. The stochastic motion model is an appropriate and fast method for analysis the dynamic pedestrian behavior. However, to derive valid results several simulation runs (>100) have to be performed. The focus concentrates on the evaluation of application oriented simulation scenarios instead of the characteristics of individual interactions or specific pedestrian trajectories.

The presented motion model is based on a stochastic approach, which is comparable to a common cellular automaton. It utilizes a regular grid structure. In contrast to the cellular automaton, the new model is developed on the basis of a fundamental paradigm shift: instead of changing the cell status depending on the status of its surrounding cells (neighbors), the agent is able to move over the regular lattice and to enter those cells, which are not occupied by other agents or obstacles (e.g. walls). To describe the motion behavior of an agent, the motion vector is separated into a desired motion direction and a transversal deviation. Using the spatially discrete grid structure and defining three transition states (forward | stop | backward or left | on track | right) the normalized transition probability (p) into these states can be generally defined and solved.

Finally, the motion components are combined to a 3×3 transition matrix. In fact, the transition matrix possesses a two-dimensional characteristic, but it only defines an one-dimensional transition considering a transversal deviation (1.5-dimensional). To allow for a three-dimensional agent motion behavior, two independent motion directions are needed. Based on a developed horizontal transition matrix a diagonal transition matrix is derived by re-indexing the horizontal matrix. The motion direction is integrated into the stochastic model by superpose these matrices. The rotation of this superposed matrix (4-fold symmetry) allows for determining the entire spectrum of the motion

direction. The underlying regular grid structure results in a direction dependent behavior (e.g. entering diagonal cells implies walking a longer way in comparison to horizontally located cells).

Due to the utilization of a regular grid structure, the transition matrix does not fulfill the criteria of independent agent motion behavior. So, the speed and the variance of the agent depend on the agent motion direction. If the agent enters diagonal cells his walking distance is longer (approx. 41%) in comparison to the use of horizontally located cells. This model constraint is equivalent to a significant higher motion speed depending on the direction of motion. Algorithms to compensate this grid-based speed effect can be found at the scientific community as well. A detailed model analysis points out that the expected value of the transition matrix, defined by cell based transition probability and the relative location differs from expected value which is specified in the motion model.

The angle depended variance of motion implies two major issues. So, the basic model shows an immanent motion deviation, which is not considered in previous equations and the different variances lead to different avoiding behavior. Using the same scenario but with a different motion angle, the agent gets drifting probabilities to pass blocked cells. To ensure homogeneous variance distribution, an appropriate compensation on model level is needed. The expected value of the matrix depends on speed and standard deviation, whereas the parameters are directly coupled. For each parameter set a specific characteristic over the angle has to be calculated.

Further model investigations point out that the model has to be extended to reproduce the representative shape of the fundamental diagram. Using the transition matrix, an agent is able to react to the status of the adjacent cells (empty, occupied). The fundamental diagram indicates an interaction range of about 1.3 m, because the speed of an agent starts to decrease if the density relations reaches a level of 10% maximum density (considering an agent with a dimension of 0.4x0.4 m and a maximum density of 6.25 pedestrian/ m²). If the agent moves three/four steps at once, he will be able to interact with distant agent and the developed model is found to reproduce the characteristic shape of the fundamental diagram. Therefore the motion model has to provide the following agent properties:

- Always move, no waiting (occupied cells increase transition probability of the other matrix cells).
- Move four steps at once and decrease the steps depending on agent density, at least in the case of 60% of the maximum density the number of steps should be reduced from four to three to fit the fundamental diagram.
- Agent leaves a trace, at each time step all entered cells will temporarily blocked.

The stochastic model meets all criteria for a scientifically reliable motion model. It exhibits the absence of significant model-caused limitations and reproduces all common self-organizing effects (e.g. row formation or oscillation). Besides the operational motion definition by the stochastic transition matrix, strategic/tactical motion components are taken into account as well. The stochastic model allows for the reaction of the agent to objects/agents at immediate vicinity. It additionally provides the capability of considering distant constellation of agents (jam) and potentially blocked bottlenecks.

SUMMARY AND OUTLOOK

Model specific parameter corrections ensure that the motion vector is equal to the expected value of the corresponding transition matrix. This issue has in particular not been considered within previous approaches. The calibrated motion model is thus the first approach, which allows for a specific stochastic description of agent movements without model restrictions. The passenger related evaluations and simulations of dispatch processes at Dresden Airport exemplarily show that the developed stochastic motion model is able to reproduce the behavior of passengers in an

appropriate way. Therefore the developed motion model is implemented in a corresponding application environment which allows for a various application, e.g. investigations regarding to group dynamic behavior or route planning in the airport terminal focused on normal operations and emergency cases.

The effects of the design factors of the train-platform interface on pedestrian movements

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BACKGROUND AND OBJECTIVE

As pedestrian simulation models are used not only in evaluation simulation but also in the planning and design of pedestrian infrastructure, it is necessary to obtain data of how pedestrians interact with external environments (e.g. how pedestrians interact with a step on the pavement). In the transport engineering, pedestrian models are often used to assess new designs of station platforms and rolling stock. One major application area is train dwelling at the station on the busy commuter line because even a tiny reduction in the dwell time can lead to a significant improvement in the line capacity in the peak time and therefore it is essential to assess various designs in the planning stage and choose the best option. In this case, the key element is the designs of the train-platform interface (e.g. door width, size of the gap between the train and the platform). However, there has been a lack of empirical data on how the design factors of the train-platform interface affect pedestrian movements. Although there have been some observational studies (e.g. Atkins, 2004; Harris, 2006; Wiggenraad, 2001), such studies have not varied design factors due to the nature of the observational study. An experimental study would be useful in order to systematically investigate how each design factor (e.g. door width) affects pedestrian movements. Therefore, we conducted a series of laboratory experiments to examine the effects of each design factor of the train-platform interface on pedestrian movements, particularly on the pedestrian flow rate.

METHODOLOGY

The experiments were carried out at Pedestrian Accessibility Movement and Environment Laboratory (PAMELA) of University College London, where a mock-up train and a platform were set up. The mock-up train was a half size of a real train carriage. The experiment lasted five days, and around 120 participants joined each experiment day. In total, 224 runs were conducted. The experiment was representation of a crowded commuting situation.

In the experiment, the following design factors were investigated:

- the door width,
- the size of the seat set-back (the distance between the door edge and the adjacent seat)
- the size of the vertical gap between the train and the platform, and
- the size of the horizontal gap between the train and the platform.

In each run, 50 passengers made movements whereas others stayed in the train or on the platform. Various pedestrian movement patterns were tested, namely: alighting-dominant (45 pedestrians alighted whereas 5 pedestrians boarded), boarding-dominant (45 boarded, 5 alighted) and even-alighting-boarding (25 alighted, 25 boarded).

RESULTS AND DISCUSSION

As we are still analysing the data, this section shows some preliminary results of the experiments. We will finish the data analysis before the deadline of the paper submission and in the paper we will publish the results of our analysis.

First, a larger doorway increased the pedestrian flow rate. Performance of the alighting-main runs especially improved when the doorway was increased from 1500mm to 1800mm. This may be related to the human body size. The shoulder breadth can be assumed to be 600mm (Transportation Research Board, 2010), but it may be necessary to have a doorway of more than 1500mm in order to achieve two streams at the door because some non-alighting passengers in the train stood still next to the door. A doorway of 1800mm may make this possible. Because alighting essentially requires two streams of passengers from the seating spaces on both sides of the door, having two streams at the door would improve the alighting flow rate.

Secondly, a greater the size of the vertical gap between the train and the platform led to a less flow rate. Alleviating the vertical difference from 250mm to 50mm would improve around 10% when boarding is the main, whereas the alighting-main runs showed a slight improvement only. A possible reason for this would be that, as the train floor is at a higher level than that of the platform, the boarding movement requires each pedestrian to lift his/her body to a higher level and this body movement could slow down the flow rate.

CONCLUSION

As the application areas of pedestrian simulation models increase, more empirical evidence is necessary to support the calibration and validation of models. In the transport engineering discipline, evidence on how each design factor of transport infrastructure affects pedestrian flow is essential. The results of our experiments provide useful data and insights into the pedestrian movements at the train platform interface.

REFERENCES

Atkins, 2004, Significant Steps – Research, Research commissioned by UK Department for Transport

Harris NG, 2006, Train boarding and alighting rates at higher passenger loads, Journal of advanced transportation, 40(3) 249-263

Transportation Research Board, 2010, Highway Capacity Manual: 2010, Transportation Research Board, Washington

Wiggenraad PBL, 2001, Alighting and boarding times of passengers at Dutch railway stations, TRAIL research School, Delft University of Technology

Including route choice models into pedestrian movement simulation models

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Currently route choice in pedestrian movement simulation models (PMSMs) predominantly is limited to the assumption of shortest route objective (Kretz 2009). This neglects the fact that persons not familiar with the infrastructure have difficulties finding the shortest path and try to follow signage (Schrom-Feiertag and Matyus, 2011). Moreover it is known that pedestrians use a variety of criteria for route choice (Golledge 1995).

This paper provides more evidence gathered using two experiments conducted during a workshop at AIT and proposes a model for route choice to include the corresponding results. 25 individuals, all experts in pedestrian modelling, had to conduct two route choice related tasks. The first task consisted in drawing a route on a map of the city of Graz connecting a start point with an end point while passing eight intermediate goals. The instructions stated that all available roads could be used and did not in any way indicate the objective to be used for route choice. No subject was familiar with the city. Out of the 25 persons, three persons did not complete the task correctly leaving a sample of 22.

The routes were quantized using a number of criteria taken from (Golledge 1995) including length of the route, number of corners, extent of retracing its own route, percentage of length on main routes (the Teleatlas map shows main roads in yellow, minor roads are drawn in white), number of times (out of nine possibilities for the eight intermediate and the final goal) the longest leg occurred first in the corresponding route segment. Since the retrace ratio and the number of longest leg first did not appear to contain information relevant for clustering the individuals, they were excluded from further analysis. After normalizing each of the remaining three criteria to $[0,1]$, a k-means clustering algorithm with five clusters (selected using the typical information) was applied. The five clusters found can be given the following interpretation: One cluster containing only two individuals is characterized by excessive route length and a large number of corners. This cluster was classified as outliers. One cluster (three people) is characterized by a high percentage of main roads and comparatively few corners. Two clusters show the shortest routes and differ in high usage of main roads (4 people) and small number of corners (5 people). The remaining cluster was the largest, containing eight people with no apparent objective being followed.

A more detailed analysis of their routes showed that the higher route length was not a consequence of the chosen order of the intermediate goals but rather the failure to find the shortest connection between these.

This conjecture was confirmed using the second experiment which asked the pedestrians to walk along a route connecting five (out of eleven) given symbols randomly placed on the floor of an otherwise

empty hall. Here finding the shortest path between two symbols is trivial. No statistically significant differences in route lengths between the last three clusters could be found.

This behaviour must be reflected in the routing component of PMSMs. The classical social force model (Helbing and Molnar 1995) includes the definition of a not further specified goal that needs to be set by the model for each agent in each time frame. This leaves room to incorporate different agent behaviour including agents unfamiliar with the infrastructure or agents that use full information. In the latter case the results above suggest that the population needs to be split into two segments, agents who maximize staying on major roads and agents who want to minimize walking length.

To this end a graph of the infrastructure is constructed connecting intermediate goals as nodes. Further a classification into major edges and minor edges must be taken on the basis of usage characteristics (such as the width of corridor, means of level changes) as well as signage inside the infrastructure (edges which coincide with the intended routes according to signage being major roads). Secondly also a partitioning into major and minor nodes must be taken, where major nodes mark entries to buildings or points of level changes inside the infrastructure (such as elevators, escalators and stair cases). All other nodes are seen as minor nodes, implementing a hierarchy in route choice where first choices on the upper level are made and for given sequence of major intermediate goals route choice on the lower level is performed.

The corresponding route choice can be modelled using a nested C-logit formulation on this graph which is standard in traffic flow modelling. Consequently general traffic flow modelling can be applied including route choice under congestion by using user optimal assignment. As for pedestrian infrastructures the corresponding graph will be relatively small, implementation of such a route is straightforward.

This paper only is a first step into this direction in the sense that the main idea is discussed and supported by empirical observations. The sample size in the experiments, however, is too small in order to provide even magnitudes of the percentages of persons using a particular routing strategy. Thus future work will be directed into the assessment of the percentages of persons using route length minimization or percentage on main roads as their objective function in different real world settings.

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REFERENCES

- Golledge, R. G. 1995. "Defining the criteria used in path selection." *Transportation* 278, 151-169
- Helbing, D., and P. Molnar. 1995. "Social Force Model for Pedestrian Dynamics." *Physical Review E* 51: 4282-4286.
- Kretz, T. 2009. "Pedestrian traffic: on the quickest path." *Journal of Statistical Mechanics: Theory and Experiment* 2009.
- Schrom-Feiertag, H., Matyus, T. 2011. „Simulation of handicapped people finding their way through public buildings." *Abstract submitted to the PED2012 conference.*

Dynamic medium scale navigation using dynamic floor fields

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Microscopic pedestrian simulations are an emerging topic in all phases of the design and operation of infrastructures, e.g. airports. Applications range from an optimal design of airports with respect to passenger comfort to evacuation of building in the case of emergency. To ensure a maximum of reliability of simulations these have to yield as realistic results as possible.

Navigation in existing microscopic pedestrian simulators can be distinguished into three different levels. On a large scale level pedestrians navigate from one point of interest to the next to their final target, e.g. from crossing to crossing. On this level other pedestrians are taken into account only very coarsely, since typically the way cannot be observed completely. On a medium scale level, pedestrians navigate from their current position to the next point of interest, which we will refer in the following as an intermediate target. Depending on the densities other pedestrians are taken into account on this navigation level, i.e. if pedestrians see dense crowds they adapt their route immediately trying to move around the crowd. On a small scale level pedestrians adapt their route trying not to collide with other pedestrians, which we will refer as short scale navigation. Here, pedestrians in the direct neighbourhood are taken into account.

Most pedestrian simulators take other pedestrians only on the large and small scale into account. On the medium scale other pedestrians are neglected and a static navigation field is considered. Considering low to medium densities typically good and relative realistic results are obtained. In the case of high pedestrian densities this is however not always the case. Only very few simulators use dynamic medium-scale navigation taking other pedestrians into account (Burstedde Klauk Schadschneider & Zittarz 2001, Ketz 2009, Hartmann 2010). Since recently effective computational techniques have been proposed for constructing appropriate dynamic floor fields (Hartmann 2011), the simulation of large dense crowd has become well in reach.

In this paper, we will outline in detail a modification of the method proposed in (Hartmann 2010). This allows that not only unnatural congestions are avoided, but also realistically captures effects like lane formation in dense crowds. Instead of considering a repulsion of pedestrians on a short and medium scale independent of the walking direction, the method takes walking directions into account. On the short scale navigation is similar model has been realized in many different approaches, e.g. (Helbing & Molnár 1998). On the medium navigation level, directions of other pedestrians are typically not taken into account. Here other pedestrians and their walking directions are taken into account based on a dynamic recalculation of the navigation floor field using pedestrian repulsion potentials adapted to relative walking directions of pedestrians.

The approach does not need an additional floor field as required by the approach of (Burstedde Klauck Schadschneider & Zittarz 2001). Furthermore the approach is as efficient as the methods outlined in (Kretz 2009) and (Hartmann 2010), but simultaneously captures typical effects like lane formation. The strength of the approach is demonstrated by simulating the different scenarios outlined in (Helbing, Molnár, Farkas & Bolay 201) and successfully reproducing the described effects of lane formation in many different situations.

Using more efficient strategies than the strategy presented in (Hartmann 2010) for moving along gradients of the floor field, as well as more elaborate algorithms for continuously updating floor fields, the method is nearly as efficient as classical floor field based approaches to microscopic pedestrian simulators. However, the extensions of the model allow significantly more realistic simulation results and thus a better prediction of pedestrian flows and egress times.

Thus the method is a promising candidate to replace the medium scale navigation layer in the multi-level pedestrian simulator outlined in (Kneidl Hartmann Borrmann 2011)

REFERENCES

Burstedde, C, Klauck, K., Schadschneider, A. and Zittarz, J.. 2001 Simulation of pedestrian dynamics using a two-dimensional cellular automaton. Physica A: Statistical Mechanics and its Applications 295: 507-525

Hartmann, D., 2010. Adaptive pedestrian dynamics based on geodesics. New Journal of Physics 12 (4), 043032.

Hartmann, D. and Hasel, P. 2011. Efficient floor field methods for microscopic pedestrian crowd simulations. submitted

Helbing, D., Molnár, P., Farkas, I. and Bolay, K. 2001. Self-organizing pedestrian movement. Environment and Planning B: Planning and Design 2001 (28), 361-383.

Helbing, D. and Molnár, P. 1998. Social force model for pedestrian dynamics. Physical Review E 51: 4282-4286

Kneidl, A., Hartmann, D. & Borrmann, A. 2011. Using a multi-scale model for simulating pedestrian behavior, submitted

Kretz, T., 2009. Pedestrian traffic: on the quickest path. Journal of Statistical Mechanics: Theory and Experiment 2009, P03012

Pedestrian gap acceptance in micro-simulation modelling

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This paper develops an agent gap acceptance based algorithm for modelling opportunistic agent behaviour and safer crossing behaviour at crossings using the Urban Analytics Framework (UAF). The UAF software combines the Quadstone Paramics traffic micro-simulation model and crowd/pedestrian algorithms developed by Crowd Dynamics International Limited. Unique algorithms fuse these two parts, allowing the individual vehicles and agents to interact. This allows many different geometries and behaviours to be modelled, including pedestrian crossings, shared space, pedestrian presence at signalised junctions and pedestrians who do not comply with signals and cross against a red man or 'Don't Walk' signal. However, there are also many unmanaged crossings in urban environments, where pedestrians must make a decision as to when a sufficient gap in traffic exists so that it is safe to cross. This paper will identify methods that allow this gap acceptance behaviour to be modelled in a flexible manner.

The methods developed to model pedestrian gap acceptance use the concept of scan areas. Each vehicle is assigned two polygonal shapes. The primary scan area will be the area where a vehicle will be able to see pedestrians and to slow down for them. The secondary scan area will be an area that will allow any agent inside it to consider whether to cross in front of the vehicle depending on combined gap acceptance criteria defined for the agent, vehicle and location. Both scan areas take into account individual vehicle kinematics and agent attributes. This would allow agent behaviour at unmanaged marked and refuge crossings and median strip environments to be modelled more realistically with more flexibility on defining the behaviours.

The primary scan area instructs vehicles to slow down for an agent who is within a specified area. The primary scan area is an irregular hexagon that adjoins the front of the vehicle. It is defined using four measurements: End Width (EW), Start Width (SW), Start Length (SL) and End Length (EL).

EW is based on the total number of lanes that the link on which the vehicle travelling has on both sides of the road. EW has an additional 1m width on either side of the road to ensure that agents approaching a crossing point will be seen. EL is based on the additional buffer time set in the location of the crossing.

SW is based on the width of the vehicle, but can be extended up to the end width (EW) by a percentage. This allows behaviour to be altered by allowing the vehicle to wait for agents that are at a wide angle of view from the driver, as if the driver were looking left and right; or to allow the vehicle to continue moving in a more aggressive style of behaviour; or some arbitrary parameter between the two.

SL is based on the vehicle's minimum desired stopping distance. This is taken from the secondary scan area determines whether an agent can safely enter the crossing by performing gap acceptance checks against conflicting vehicles. The shape is a trapezium that adjoins the front of the vehicle. The dimensions of this scan area are defined by four points using three measurements: Width (W), Near side Length (NSL) and Additional Length (AL).

W is based on the EW of the Primary Scan Area, which covers the whole road width with a 1m buffer to ensure approaching agents are included in the calculations.

NSL is the length of secondary scan area when the vehicle is in the lane next to the kerbline. This is the shortest length of the dimensions because it would take an agent less time to travel past the vehicle than it would if the vehicle was in any other lane.

AL is added on for each lane the vehicle is away from the kerbline. This is controlled as a percentage of the NSL and is added on for each lane that the vehicle is away from the kerbline. The AL is added on to both the nearside of the vehicle and the far side depending on which lane the vehicle is in. Agents will wait whenever they are inside a secondary scan area and approaching gap finding space. This is extremely useful for defining behaviours in a specific area allowing all agents to take similar gaps.

However, the above method does not allow for differing behaviours in agents. For example a faster moving agent may be more likely to take a smaller gap than a slower moving agent. Therefore, an additional algorithm can be used to allow the model to vary the gap choice for different agents. This is done by calculating the time taken by a vehicle to reach a theoretical collision point.

Each agent has a buffer zone which is based on the maximum walking speed of an agent. The buffer zone is the additional time which needs to be taken by an agent to cross before a vehicle arrives at the collision point.

The collision point is calculated using the current line of sight of an agent. This allows any direction of movement to be taken into account. The agent will look along the line of direction the agent is facing until an available walking area is found. This distance is used to assess if an agent is able to cross the road before the vehicle passes the collision point. This variable approach allows different agent behaviours to be modelled in the same location.

In the paper, the above approaches are developed in detail. The limitations of the algorithms with regards to type and style of crossing behaviour are identified and where possible, these are overcome by allowing a dynamic alteration of the scan area shapes.

A macroscopic multiple species pedestrian flow model based on heuristics implemented with finite volumes

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INTRODUCTION

Despite all the principle implications of applying macroscopic models to pedestrian flow simulations, there are good reasons to use them for sufficiently large crowds. The application of fluid dynamics equations proved to be of limited success, so new approaches have been sought. One promising approach has been introduced by (B. Piccoli and A. Tosin, 2011) and related and follow up work. Another approach has been taken by (S. Berres et al., 2011). These papers have a parted focus on mathematical rigor and implementational detail.

Our model has been developed with a focus on practical applicability and is intended to be rather pragmatic, than mathematically rigorous. We try to overcome at the one hand the limit that only two pedestrian species (differing in desired target and walking speed) may be handled as in the two papers mentioned above and at the other hand enforce a maximum density of the pedestrians (as required in real life situations), which seems not to be provided by the model of (B. Piccoli and A. Tosin, 2011).

MODEL

The model shall primarily simulate normal (non-panic) situations. The primary goals in mind have been:

- robustness,
- simplicity (as far as possible),
- stand alone usability and integrability with/into other models and software,
- flexibility to
 - provide for adaptability in the research process,
 - be able to serve as a module in the framework of the MATSim project (see <http://www.matsim.org/>),
 - be able to couple with a microscopic model,
- being heuristics-based to aim at catching vital features,
- being able to model a potentially unlimited number of pedestrian species.

We base our model on the following basic assumptions:

Assumption 1:

Pedestrian movement is determined by a field of influences that results in their walking direction and speed. In that model every considered aspect (like planned path to a target, obstacles, walls, other pedestrians and so on) has a foot print in the environment of the pedestrians, generating an interaction

field with distant forces or rather effects, that can be approximated continuously in space. The informational peaces of this field can be expressed by partial differential equations.

Assumption 2:

The information base, that is processed by individual pedestrians to make decisions, is not purely factual, but a perception or even a (re)constructed picture (based on the experiences of these individuals) of the reality. In the case of non-collision driven flow, the velocity and walking direction is a product of a heuristics-based decision-making process by individual pedestrians.

Assumption 3:

The heuristics, that apply in pedestrian traffic should be rather simple to be accessible by the majority of pedestrians. If several simple strategies are to be considered, the one, that proves more effective is likely the preferred one, because pedestrians are supposed to seek efficiency too.

Assumption 4:

Due to the smoothness of the controlling fields (see assumption 1), we assume, that a mass (inducing inertial behavior in the model) is not necessary. This way we assume, that the pedestrians may follow (adapt speed and direction) to the controlling fields without significant lag by means of internal impetus, decision and physical strength.

Assumption 5:

There exists a fundamental diagram, that expresses the relation between density, possible walking speed and thus flux of the pedestrians.

The starting point of our model is derived from the model in (S. Berres et al., 2011). The major adaptation (aside from dropping the two species limit), has been to replace the (cross)diffusion term (which we didn't find an appropriate interpretation for) by a total density gradient term and generating a time-dependent desired direction field for the pedestrian species.

So the transport equations are individual for each pedestrian species and are coupled by the total density. The transport velocity for each pedestrian species dissolves into two parts:

(1) an intentional direction followed dependent on the total density (according to a fundamental diagram). This intentional direction is the gradient of the solution generated by a Poisson equation and depends on:

- the geometry of the simulation area (global phenomenon)
- a jam-detection source term (global phenomenon)
- an inter-pedestrian-species attraction/repellency source term (local phenomenon)

(2) a local correction velocity dependent on the gradient of the total density.

RESULTS

The rather intermediate scale simulations produced the usually to be expected qualitative phenomena like lane formation, clustering of pedestrians and congestions for appropriate settings of parameters with up to four interacting pedestrian species. Effects, that are missing for instance, are forming of roundabouts and effects, that are based on prospective human abilities.

Due to the construction of the model, the adherence to the overall and individual pedestrian species densities has been ensured. These results have been achieved by a fairly simple set of rules.

REFERENCES

Piccoli, Benedetto and Tosin, Andrea: „Time-Evolving Measures and Macroscopic Modeling of Pedestrian Flow“, Archive for Rational Mechanics and Analysis, Springer, pp 707-738 (2011)

Stefan Berres and Ricardo Ruiz-Baier and Hartmut Schwandt and Elmer M. Tory: „An adaptive finite-volume method for a model of two-phase pedestrian flow“, Networks and Heterogeneous Media (NHM), AIMS (2011)

A simplified force model and enhanced steering for a quantitative description of pedestrian dynamics

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Force-based models are a very popular approach for modeling pedestrian dynamics which assumes that pedestrian's movement is a consequence of exterior forces acting on pedestrians. In this work we propose a space continuous force based model to describe the movement of pedestrians in 2D-space by means of forces and torques. Furthermore, the model incorporates a foresight mechanism allowing pedestrians to react on the actual as well as on a predicted situation.

Formally the movement of pedestrians is defined by N differential equations. The equation of motion is given by superposition of repulsive and driving forces. While repulsive forces keep pedestrians away from each other and other obstacles, driving forces lead them to a chosen exit with a preferred velocity.

In most force-based models [2-11] pedestrians are modeled as circles or mass points. Since the forces act on the center of mass of each pedestrian and given the point symmetry of pedestrians, the torques are zero. Therefore the movement of pedestrians is restricted to accelerations and decelerations without the ability to avoid other pedestrians. In general these avoidance maneuvers are introduced in force-based model in form of algorithmic solutions. In this work we model the shape of pedestrians as elliptical disks and enhance the generalized centrifugal force model [1]. With a proper choice of the acting point of the forces taking into account the actual volume exclusion, the direction of pedestrians is determined, by means of the aforementioned forces but also by torques that those forces produce in time.

Thus, no extra procedures to manage collisions or avoidance maneuvers are necessary. This approach leads to a realistic description of volume exclusion and short termed evasion maneuvers.

For the steering on a tactical level a new method to choose the desired direction is investigated and tested in geometries with 90° and 180° corners. The method is based on identifying automatically in a given geometry corners and set lines rotated with a certain angle around them. To avoid congestions around the corner, each line is assigned points weighted decreasingly away from the corner. In case of low densities, pedestrians are guided towards the corner. If the density gets high, pedestrians get, thanks of the weights, directed away from the corner.

Qualitative and quantitative comparisons among several experimental data and measurement methods are used to validate the steering model.

The model for the volume exclusion and steering contains only two free parameters, which benefits this procedure and facilitates its calibration.

For the sake of validation of the model for the volume exclusion we reproduce empirical data in several geometries with one set of parameter. The GCFM was successfully validated in narrow and wide corridors. For bottlenecks, corners, T-junctions and generally geometries that necessitate maneuvering, the need to model the desired direction is especially more highlighted. With the enhancements, we introduce in this work, it is possible to simulate more challenging geometries without the need of tuning and changing parameters.

In summary the proposed model reflects three aspects:

1. The repulsive force reflects the elliptical shape of pedestrians. Its magnitude is proportional to the overlapping area with other pedestrians.
2. The repulsive force engender a torque, allowing pedestrians to change easily direction.
3. The forces depend not only on the actual situation but also on an educated guess how the situation changes in the future.
4. The desired direction is modeled to enable maneuvering in complex geometries.

REFERENCES

- [1] M. Chraibi, A. Seyfried, and A. Sachdschneider. *Generalized centrifugal force model for pedestrian dynamics*. *Physical Review E*, 82:046111, 2010.
- [2] Z. Fang, J. P. Yuan, Y. C. Wang, and S. M. Lo. *Survey of pedestrian movement and development of a crowd dynamics model*. *Fire Safety Journal*, 43(6):459465, aug 2008.
- [3] D. Helbing and P. Molnar. *Social force model for pedestrian dynamics*. *Phys. Rev. E*, 51:42824286, 1995.
- [4] T. I. Lakoba, D. J. Kaup, and N. M. Finkelstein. *Modifications of the Helbing-Molnr-Farkas-Vicsek Social Force Model for Pedestrian Evolution*. *Simulation*, 81:339352, 2005.
- [5] Rainald Löhner. *On the modelling of pedestrian motion*. *Applied Mathematical Modelling*, 34(2):366-382, feb. 2010. *Article in Press*.
- [6] Daniel R. Parisi, Marcelano Gilman, and Herman Moldovan. *A modification of the social force model can reproduce experimental data of pedestrian flows in normal conditions*. *Physica A: Statistical Mechanics and its Application*, 388(17):36003608, sep 2009.
- [7] A. Seyfried, B. Steffen, and T. Lippert. *Basics of modelling the pedestrian flow*. *Physica A*, 368:232238, 2006.
- [8] B. Steffen and A. Seyfried. *The repulsive force in continous space models of pedestrian movement*. 2008. *arXiv:0803.1319v1*.

[9] B. Steffen and A. Seyfried. *Modelling of Pedestrian Movement around 90 and 180 Bends*. In B. H. V. Topping and Y. Tsompanakis, editors, *Proceedings of the First International Conference on Soft Computing Technology in Civil, Structural and Environmental Engineering*. Civil-Comp Press, Stirlingshire, UK, 2009., 2009.

[10] Albert Steiner, Michel Philipp, and Alex Schmid. *Parameter Estimation for a Pedestrian Simulation Model*. In *Swiss Transport Research Conference*, 2007.

[11] W. J. Yu, L.Y. Chen, R. Dong, and S.Q. Dai. *Centrifugal force model for pedestrian dynamics*. *Phys. Rev. E*, 72(2):026112, aug. 2005.

Quantitative and qualitative validation for general use of pedestrian models

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INTRODUCTION

Typically the application of a model includes a description of the population characteristics, the walking infrastructure and inflows. The population is usually represented internally in the model and determined via the model parameters that were obtained in an optimisation procedure during the calibration process. The infrastructure and inflows determine the type of situations pedestrian walk.

The fundamental premise for the use of pedestrian models is the confidence that their results are within an accepted deviation of reality. However, pedestrian behaviours vary according to local conditions such as densities, direction of interaction between pedestrians (walking towards each other, crossing, overtaking) and internal states determined by age, culture, purpose of the trip. The process of determining the adequacy of a model (and its parameter set) is called validation. A typical validation will compare some empirically obtained data about pedestrians with the outcomes of the model. Ideally the comparison (assessment) is performed reproducing similar population characteristics, walking infrastructure and inflows. A literature research on validation of pedestrian models showed that usually authors perform a limited amount of validation assessments and very few considerations are given regarding the applicability of the model in different walking situations and population characteristics. We argue that if no parameter set is calibrated for the specific task, the set to be used must have shown to perform well in various validation assessments utilising several walking situations giving a measure of general usability.

This paper proposes a simple and meaningful criterion to combine qualitative and quantitative validation assessments to obtain a measure of validation quality. Applying this method with the microscopic Nomad model developed by the Technical University of Delft, resulted (as expected) that parameter sets that were calibrated with flows that expose pedestrians to different situations and optimised with several calibration assessments (multi-objectives) are more accurate and present more realistic pedestrian behaviour.

METHODOLOGY

The validation ends with a general score obtained after combining the results of all the assessments. Each assessment resulted in a score that ranged between, bad, medium and good. The quantitative assessments were graded according to the size of the relative errors of the simulated results: bad:= error > 10% medium:= 5% < error < 10% good:= error < 5%. Each qualitative assessment was assigned one of the scores according to their resemblance to the empirical data. The combination of the scores is done using a simple averaging procedure performed after grading the scores. The bad score gets a grade 0, the medium gets 1 and the good gets 2. An average of the grades was then tabulated between

three intervals of equal length to calculate the final score. This very simple procedure was chosen to diminish the complexity of the validation procedure allowing for a simple interpretation of the results. To increase the importance of the quantitative assessments in the final score all qualitative assessments were combined into one score and then added to all quantitative assessments to obtain the final average grading.

The validation assessments performed in this paper used data from three trajectory sets obtained in controlled walking experiments (Daamen 2003). These sets cover different types of flow: a bidirectional corridor, a unidirectional corridor and a unidirectional flow with narrow bottleneck corridor. These flows represent many walking situations and are most often used in validation assessments.

The three most common types of validation assessments found in the literature, travel times, speed x density fundamental relation and bottleneck capacity estimation were quantified. The qualitative validation judged the interaction and walking behaviours. Furthermore, for the bidirectional flow we qualified the duration and stability of the self-organised lanes. The narrow bottleneck experiments presented two distinctive situations, upstream of the bottleneck congestion builds up forming a funnel of pedestrians with the apex located in the bottleneck and downstream where pedestrians walk inside a narrow corridor in a staggered positioning also referred as the self organizing zipper effect. Both phenomena were also used for the qualitative validation.

We compare the results of eight parameter sets that were calibrated with different objectives over trajectory sets representing the three flows. Two objective functions, the travel time's errors (TT) and the acceleration error at walking steps (Ac) were used with the three trajectory sets totalling the six specialised parameter sets. The other two sets are general; the multiTT was optimised using a multi-objective function that combined the travel time's errors of the three types of flow. The multi is even more general because it was optimised with different objective functions for the three flows. The characteristics of each flow were explored in the calibration, the quantity of lanes, the speed x density relation and the bottleneck capacity. Each assessment was performed 30 times to account for the stochastic variations of the model and the results were averaged.

RESULTS AND DISCUSSION

The first important result was that the stochastic variation of the assessments using the general parameter sets was significantly smaller. The reason for this was found in the significantly better behaviour of the pedestrians. Both general sets obtained better qualitative scores that measured the interactions, the multi set obtaining the maximum score in all three flows. The overall score of the general sets were identical with one good and two mediums, always better (or equal) then the specialised sets for all flows. Considering that the specialised sets were validated to flows identical to those used in their calibration, these results are very important. They indicate that pedestrian behaviours are so complex that the calibration using one type of flow and one assessment is over fitting the parameters and that combining several aspects of walking behaviours approximate better to a global optimum of predictions. The unidirectional flow obtained the best validation results (all sets obtained a medium) and also the best qualitative reproduction of individual behaviours (two goods and two medium). The speed x density assessment gave the worse results for all sets and all flows. This was mostly due to the difficulty of achieving the same maximum densities in the simulations of the bidirectional and the unidirectional flows and the large data scatter. These variations in the value of the assessments clearly show the independence of them. Presenting good results for one is no guarantee that the same will happen with the other assessments.

CONCLUSION

This paper proposed a new and very simple validation procedure that combines qualitative and quantitative assessments. Spite its simplicity it was able to show that several assessments effectively reveal the differences in accuracy between parameter sets. The good results for the validation of the unidirectional flow when the same did not happen for the others show that this type of flow should not be relied solely in a validation. It should always be accompanied by other type of flows that are more challenging for pedestrian models. Sets optimized with multiple-objectives simulate better walking behaviours and diminish the variability of the results. The smaller variability and the better accuracy make them more suited to be used in simulations and should accompany all pedestrian models. These results strongly encourage the pursuing of accuracy in a wide range of situations (generality).

REFERENCE

Daamen, W. and Hoogendoorn, S. (2003). Controlled experiments to derive walking behaviour. European Journal of Transport and Infrastructure Research, 3(1):39–59.

FDS+Evac model validation for seated row arrangements

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The open source software Fire Dynamics Simulator (FDS, version-5.5.3) is one of the most advanced computational fluid dynamics based fire simulation software available to model practical fire problems. FDS has got another powerful tool which is capable of simulating human egress process with and without the effects of fire under the name of FDS+Evac. The human movement algorithm of FDS+Evac has been validated with experimental evacuation data and other evacuation models. But it is not yet validated on how to model evacuation process for seated row arrangements like aircraft, auditorium etc. Here an attempt has been made to model evacuation of humans in seated row arrangements with the help of two known experimental data, i.e., evacuation studies of a blended wing body aircraft (BWB) and a cinema theatre. The fire drill evacuation tests were modelled using FDS+Evac and validated with the experimental data and other human egress models.

A blended wing body aircraft (BWB) configuration consists of 1020 passengers, with 25 cabin crews and 20 floor level Type-A exits. The exits present on the right hand side of the aircraft from front to rear are denoted as R1 to R10 and on the left hand side as L1 to L10 respectively. The test case considered here was a standard evacuation certification case where half of the usable exits are blocked, i.e., 10 out of 20 exits were made available on the left side (L1 to L10) of the aircraft and a standard opening time of 11.1 sec for Type-A exits is used. Considering full-scale trials involving over 1000 people is expensive, so Galea et al. [E. R. Galea, L. Filippidis, Z. Wang, P. J. Lawrence, and J. Ewer, Evacuation analysis of 1000+ seat Blended Wing Body aircraft configurations: Computer Simulations and Full-Scale Evacuation Experiment, Pedestrian and Evacuation Dynamics, Springer, pp. 151-161, 2011.] decided to undertake full scale trials using a portion of BWB cabin. A total of 375 passengers evacuated with access to exits L6 to L10 on the rear side of the aircraft. Some 88 participants were seated in the mockup and 146 participants were brought into the mock-up section via two cross aisles feeding the mock-up section.

Since the BWB cabin layout information with internal dimensions, aisles width, seat dimensions etc. are not available in that paper, the cabin was modeled only using the available information of the aircraft model presented in their paper. Initially, the BWB layout considered in this work has the space in front of doors as 1.0m, vertical aisles width as 1.0m and horizontal aisles width as 1.0m. A total of 11 BWB test cases (BWB, BWBTC1 to BWBTC10) are considered by varying the above dimensions from 1.0m to 1.25m, and 1.5m and evacuation time is calculated for all the cases. It was noticed that the variation of horizontal aisles width did not effected the evacuation time much. The final layout accepted is BWBTC6, i.e., space in front of doors as 1.5m, vertical aisles width as 1.5m and horizontal aisles width as 1.0m. The predicted average exit usage from FDS+Evac is compared with Air-Exodus model and it has shown similar trends in exit usages. The modeled BWBTC6 layout is compared to

the experiment and the trends of predicted average exit usage look similar. We have noticed that the average exit usage of passengers is more for the exit-L10 in FDS+Evac and more for exit-L6 in Air-Exodus model when compared to experimental data. Since the passengers are moving from the right wing to left wing they choose the nearest exit which is the exit L10. The exit-L7, which is present at the back corner, is the least used by the passengers and both models predicted this well.

The cinema theatre consists of 135 participants with two exits one at the front side and one at the back side. It consists of nice rows with fifteen seats each. The space for human movement is present on the each side of the seat rows as steps from front to back. A series of evacuation experiments were conducted in a cinema theatre to investigate the social influence during emergency evacuation. The purpose of these experiments was to test how different alarms effect the pre-movement time. The different alarms tested by Nilsson and Johansson [D. Nilsson and A. Johansson, Social influence during the initial phase of a fire evacuation - Analysis of evacuation experiments in a cinema theatre, Fire Safety Journal 44, pp. 71-79, 2009.] were alarm bell and pre-recorded human voice. The pre-movement times were also recorded in the experiments. The above experimental case was also validated using STEPS and SIMULEX models.

The layout information of the cinema theatre is 11.5 m x 10 m with two 0.8 m wide exits and 1.0 m free space for human movement on either side of the seat rows. The space in between the seat rows is 0.5 m and dimensions of seat are also known. The cinema theatre model was developed from the above known information using FDS+Evac. The experimental pre-movement time is given as input to the FDS+Evac. We have noticed that the FDS+Evac is able to predict the total evacuation time nicely along with other models. The FDS+Evac model prediction on number of humans present in rows 2 to 9 at the times 40, 50 and 60 sec after activation of alarm are close to experimental data.

The FDS+Evac model is validated for seated row arrangements by considering two experimental evacuation cases. FDS+Evac is able to predict well for both the cases. Though much information on the pre-movement times was not provided in the case of aircraft, it was noticed that the motive force for human evacuation in aircraft is faster when compared to the cinema theatre. The FDS+Evac, PERS name list, which takes care of input parameters like human speeds, pre-evacuation times and social influence forces etc. for the aircraft and the cinema theatre cases are presented in this paper.

Keynote

Wednesday, 6 June - 14.30

Uwe Hanebeck, Karlsruher Institut für Technologie KIT, Karlsruhe GERMANY

Multimodal extended range telepresence in pedestrian simulation

Extended range telepresence provides an intuitive way to explore real remote or virtual environments. The feeling of presence is achieved by visual, acoustic, and haptic sensory information recorded from the target environment and presented to the user on an immersive display. In order to use the sense of motion as well, which is especially important for human navigation and path finding, the user's motion is tracked and transferred to the teleoperator, e.g., a mobile robot or a virtual avatar, in the target environment. As a result, in extended range telepresence the operator can additionally use its proprioception, i.e., the sense of motion, to navigate the teleoperator by natural walking, instead of using devices like joysticks, pedals, or steering wheels.

Without further processing of the motion information, the motion of the operator is restricted to the size of the user environment, which is limited, for example, by the range of the tracking system or the available space. Motion Compression solves this problem by mapping the desired path in the target environment to a feasible path in the user environment by minimizing proprioceptive and visual inconsistencies.

By connecting this extended range telepresence system to a pedestrian and vehicle simulation software, data about pedestrian dynamics can easily be collected in experiments in which not all participants need to be real people but instead some of them can be simulated. This not only allows the collection of data about pedestrian dynamics but also to calibrate model-specific parameters.

In this talk, an overview of the benefits of extended range telepresence, for example, for investigating route choice behavior in evacuation situations and for finding realistic parameters in pedestrian simulations is given. Moreover, this talk presents recent advances in extended range telepresence including haptic guidance methods and a wireless user environment.

Oral presentations

Wednesday, 6 June - 17.10

- A.10 *Matthias Plaue, Technische Universität Berlin, Berlin GERMANY*
On measuring pedestrian density and flow fields in dense as well as sparse crowds
- A.11 *Stéphane Bonneaud, Brown University, Providence RI USA*
An empirically-grounded emergent approach to modeling pedestrian behavior
- A.12 *Sebastian Burghardt, Bergische Universität Wuppertal, Wuppertal GERMANY*
Fundamental diagram of stairs: Critical review and topographical measurements of density and flow
- B.10 *Kevin Rio, Brown University, Providence RI USA*
A data-driven model of pedestrian following and emergent crowd behavior
- B.11 *Christian Rudloff, AIT Austrian Institute of Technology, Wien AUSTRIA*
Comparison of different calibration techniques on simulated data
- B.12 *Michael Schultz, Technische Universität Dresden, Dresden GERMANY*
Individual assessment of conflict prediction and group dynamic behavior as main driver for pedestrian dynamics

On measuring pedestrian density and flow fields in dense as well as sparse crowds

Matthias Plaue, Technische Universität Berlin, Berlin GERMANY

Günter Bärwolff, Technische Universität Berlin, Berlin GERMANY

Hartmut Schwandt, Technische Universität Berlin, Berlin GERMANY

In the framework of macroscopic human crowd models, pedestrian dynamics are described via local density and flow fields. In theory at least, these density and flow fields are often required to have a certain degree of regularity such as being smooth. Empirical data of human crowd behaviors, on the other hand, are usually represented by the pedestrians' trajectories. Probably the most basic way to compute a density from such trajectories would be to divide the number of pedestrians in a given region by the area of that region, at a given point in time. However, this „standard“ density estimator yields data with large scatter - let alone a smooth density function defined at every point. Very similar problems occur when estimating the flow by counting pedestrians passing through a given cross section.

At least two approaches for measuring the (local) density have been suggested in the literature as alternatives:

- In (Helbing et al., 2007), a local density field is computed via the sum of Gaussians with fixed standard deviation (typically 0.7 m) centered at each pedestrian. This approach may be recognized as a kernel density estimation with fixed bandwidth, which is a basic tool in statistical data analysis (see (Silverman, 1986), for example). This method results in a smooth density field defined at every point. Of course, the kernel estimator yields the same result as the standard density when spatially averaged across large regions. However, for an area of „mesoscopic“ size one typically observes values that are significantly lower than the standard density since a large portion of the „pedestrian mass“ is located outside of the respective region.
- (Steffen and Seyfried, 2010) propose two similar estimators based on the Voronoi diagram defined by each pedestrian's position as a Voronoi site. The main idea in this approach is to account for the personal space occupied by each pedestrian, and this personal space is represented by the area of the corresponding Voronoi cell. The values for the Voronoi density are very close to standard densities, but with significantly less scatter. However, the Voronoi estimator does not yield a smooth local density defined at every point. Also, for very sparse and unconstrained crowds, a large number of Voronoi cells may fail to have finite area, leading to conceptual issues.

In this paper, we describe a method for calculating a local density based on kernel density estimation with variable bandwidth. The method is similar to the estimation technique we previously described in (Plaue et al., 2011), but yields densities which are also temporally smooth and account for multiple nearby pedestrians as an influence on personal space.

Our algorithm is conceptually a blend of the Voronoi estimator (accounting for personal space) and the fixed-bandwidth kernel estimator (yielding smooth density fields). It may be summarized as follows:

- (1) For each pedestrian, calculate a kind of weighted average of the distances to each of the other pedestrians. The larger the number of nearby pedestrians, the lower this value will be; this may be seen as a model for the compression and relaxation of each individual's personal space.
- (2) For each pedestrian, use the value computed in Step (1) as the bandwidth of a Gaussian centered at the pedestrian's position. The Gaussians are narrower in a crowded neighborhood, and therefore less pedestrian mass is located outside of dense mesoscopic regions. This in turn leads to a better agreement with the standard density estimator for such regions.
- (3) Obstacles and walls may be modeled by multiplying the Gaussian with a mollified characteristic function with respect to the total observational area.
- (4) Renormalize and sum the (modified) Gaussians to obtain the local density.

Furthermore, as another extension of our previous work, we also specify how to calculate a corresponding flow field:

- (5) Compute the weighted sum of the pedestrians' velocities via the (modified) Gaussians computed above. This yields a pedestrian mass flow component similar to the local velocity estimator described in (Helbing et al., 2007) but with variable bandwidth.
- (6) Compute an additional irrotational flow component such that the continuity equation is satisfied. This task is achieved by numerically solving a Poisson equation. If obstacles or walls are not accounted for, this flow component may be computed explicitly in a closed form. From this closed form it may be readily seen that the additional flow component is best interpreted as the transport of pedestrian mass via the compression or relaxation of personal space.
- (7) The sum of the flow components computed in (4) and (5) represents the total flow.

In order to evaluate our approach and compare the different techniques, we use a data set of intersecting pedestrian flows extracted from human crowd experiments that we conducted at the Technische Universität Berlin. In one particular experiment, two pedestrian flows (142 and 83 subjects) intersect at an angle of 90 degrees for one minute in a region of about 25 square meters, reaching peak densities of about four pedestrians per square meter.

We demonstrate that the estimation technique proposed by us has the following advantages:

- The density and flow field are represented by smooth functions defined at every spatio-temporal point.
- The density and flow field satisfy the continuity equation.
- The density estimator typically yields values close to the standard density.

Finally, we argue that the proposed model may be interpreted as to not only describe the transport of pedestrian mass via particle flow but also as the result of variations in the pedestrians' personal space in crowded situations. We speculate that this approach may lead to new ways in describing crowd disasters which may be thought of as events where a sudden compression of personal space occurs.

REFERENCES

D. Helbing, A. Johansson, and H. Z. Al-Abideen: „Dynamics of crowd disasters: An empirical study“, Phys. Rev. E 75, pp. 046109 (2007).

M. Plaue, M. Chen, G. Bärwolff, and H. Schwandt: „Trajectory extraction and density analysis of intersecting pedestrian flows from video recordings“, Proc. PIA11, LNCS 6952, 285-296 (2011).

B. W. Silverman, „*Density Estimation for Statistics and Data Analysis*“, Chapman and Hall (1986).

B. Steffen, A. Seyfried: „*Methods for measuring pedestrian density, flow, speed and direction with minimal scatter*“, *Physica A* 389, pp. 1902-1910 (2010). Frantzich, H., *En modell för dimensionering av förbindelser för utrymning utifrån funktionsbaserade krav*, Tech. rep., Department of Fire Safety Engineering, Lund University, (In Swedish) (1994).

An empirically-grounded emergent approach to modeling pedestrian behavior

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A critical issue for pedestrian and crowd simulation is the lack of empirical validation of the behavioral locomotion model. The ability to accurately reproduce pedestrian locomotor dynamics is necessary for crowd modeling, urban planning or disaster management. But, relying on simulation requires realistic models of pedestrian locomotor behavior. Most existing pedestrian models have been based on ad-hoc rules of interaction and parameters, or on theoretical frameworks like physics-inspired approaches that are cognitively questionable. Furthermore, it is extremely difficult to validate a model in all possible scenarios. Hence, we argue with others that a more cognitive science approach is needed (Moussaïd et al. 2011). And we propose here an empirically-grounded model of human locomotion motivated by the cognitively-plausible ecological approach to perception and action (Gibson 1986). To build a reliable behavioral model, one may either experimentally derive the local control laws for locomotor behavior, yielding a generative model, or measure and try to reproduce global crowd parameters. Yet, though a model might reproduce crowd parameters, individuals trajectories can still be unrealistic. We argue that a generative model will not only produce accurate trajectories at the individual level, but is also likely to yield realistic emergent crowd behavior.

In this presentation, we first lay down the theoretical framework of the approach. Then, we describe the control laws of four elementary locomotor behaviors. Finally, we show how the model can be used in agent-based simulations of complex scenarios. We study how our model behaves with many stationary obstacles and many interacting agents. We discuss the performances of our model, in terms of behavioral patterns and computational performances, in the context of computer simulation and animation.

Based on the behavioral dynamics framework (Warren 2006), we built a locomotion model that accounts for how a human steers towards a stationary or moving goal and avoids stationary or moving obstacles (Warren 2008). The approach is emergent, i.e. the locomotor trajectory is not described by an internal planning process, but emerges from the interactions of the individual agent with its environment. Our theoretical framework is the ecological approach to perception and action (Gibson 1979), where the individual is coupled to its environment through control variables and behavioral strategies to control its actions. Based on the dynamical systems approach to action (Kugler & Turvey, 1987; Kelso 1995), interactions are described with dynamical systems and the locomotion dynamics is therefore a continuous path in the state space of the system. To infer and validate the hypotheses on the information and behavioral strategies used by humans to locomote in space, we use observations done in real or virtual worlds through controlled experiments involving human participants. We then yield control laws of locomotion, which specify behavior in terms of a dynamical control of perceptual variables. Both the theory and the empirical observations enabled us to describe a parsimonious model

using the environmental information and behavioral rules that humans seem to use when locomoting in an environment.

We propose to decompose locomotion into a set of elementary behaviors that can be modeled individually. As a first approximation, these include (a) steering to a stationary goal, (b) avoiding a stationary obstacle, (c) intercepting a moving target, and (d) avoiding a moving obstacle. Our strategy (Fajen & Warren 2003) is to model each elementary behavior as a nonlinear dynamical system and then attempt to predict human behavior in more complex environments by linearly combining these components. Based on human locomotion experiments, we determined the behavioral variables as the heading (φ) or direction of travel of the agent (allocentric reference), and the current turning rate ($\dot{\varphi}$), assuming for the moment a constant speed of travel v . The simplest description of steering toward a stationary goal is for the agent to bring the target-heading angle to zero ($\beta = \varphi - \psi_g = 0$) as it moves forward, which defines an attractor in state space at $[\varphi, \dot{\varphi}] = [\psi_g, 0]$. Conversely, for a stationary obstacle that lies in a bearing direction (ψ_o) with respect to the reference axis, at a distance d_o , the simplest description of obstacle avoidance is to magnify the obstacle-heading angle ($\varphi - \psi_o > 0$), which defines a repeller at $[\varphi, \dot{\varphi}] = [\psi_o, 0]$. Steering toward a moving goal is a generalization of the stationary case, and the goal for the agent is to keep a constant bearing with the target as it moves forward. Conversely, for a moving obstacle, the agent follows the inverse strategy by avoiding a constant bearing with the obstacle.

After showing the dynamics of the model in elementary scenarios of interaction, we show that the experimentally-grounded control laws generalize to more complex scenarios. We study five classic scenarios. Three focus on interactions between pedestrians walking in a corridor: (1) Two pedestrians walking towards each other, (2) one pedestrian walking towards a group, and (3) two flows of pedestrians walking in opposite directions. The last two scenarios focus on a pedestrian finding its way on a crowded plaza with (1) N stationary obstacles and (2) M agents walking in various directions. For each scenario, we show how our model generates realistic individual dynamics in respect to the results obtained in the elementary scenarios. Scenario 3 also shows how our model is capable of producing self-organization phenomena like lane formation. And the two last scenarios show how crowd dynamics can emerge based on our simple control laws.

This model, based on empirical data and motivated by a cognitively plausible theory, generates individual trajectories that accurately match elementary human behaviors. It is not only reliable at the individual level, but also produces realistic emergent crowd behavior. The aim is to empirically determine the minimum set of components needed, but additional components may be required to account for behavior such as herding. We discuss our current investigations of new control laws for understanding collective behavior through new experiments on leader-follower interactions and small groups of pedestrians walking towards a common goal (Bonneaud et al. 2011).

REFERENCES

Bonneaud, S., Rio, K. & Warren, W. H. (2011). *Accounting for patterns of collective behavior in crowd locomotor dynamics for realistic simulations. Transactions on Edutainment (IN PRESS)*.

Fajen, B. R., & Warren, W. H. (2003). *Behavioral dynamics of steering, obstacle avoidance, and route selection. Journal of Experimental Psychology: Human Perception and Performance, 29(2), 343-362.*

Gibson, J. (1986). *The Ecological Approach to Visual Perception*. New York, NY: Psychology Press.

Helbing D., Farkas I. & Vicsek, T. (2000). *Simulating dynamical features of escape panic*. *Nature*, 407, 487-490.

Kelso, S. (1995). *Dynamic Patterns: The Self-Organization of Brain and Behavior (Complex Adaptive Systems)*. Cambridge, MA: The MIT Press.

Kugler, P.N., & Turvey, M.T. (1987). *Information, natural law, and the self-assembly of rhythmic movements*. Hillsdale, NJ: Lawrence Erlbaum Associates. (Chapter 1).

Moussaid M., Helbing D. & Theraulaz G. (2011). *How simple rules determine pedestrian behavior and crowd disasters*. In the proceedings of the National Academy of Sciences of the United States of America, 108(17), 1-5.

Warren, W. H. (2006). *The dynamics of perception and action*. *Psychological Review*, 113(2), 358-89.

Warren, W.H. & Fajen, B.R. (2008) *Behavioral dynamics of visually-guided locomotion*. In A. Fuchs & V. Jirsa (Eds.), *Coordination: Neural, behavioral, and social dynamics*. Heidelberg: Springer.

Fundamental diagram of stairs: Critical review and topographical measurements of density and flow

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One consequence of urbanization is the growing complexity of buildings. Tall skyscrapers and underground railway stations are common buildings in large cities, therefore stairs have to be considered as part of the egress routes.

The fundamental diagram is the basic relation to characterize transport properties of traffic systems. For stairs there is no consensus which are the most important factors influencing this relation. Some handbooks distinguish between up- and downwards motion [1, 3, 4], others focus on the slope of stair [2]. Of course, the flow-density relation for different geometries is important, but the availability of microscopic analysis also offers the opportunity to take a deeper look at influences of measurement method and selected measurement area. Thus further analysis like spatial and temporal development of the basic quantities velocity, density and flow could be considered. Up to now, these influences are not scrutinized and the fundamental diagram for stairs, even the shape of the function, hasn't been understood. E.G. it is assumed, that congestion in front of stairs appears due to lower capacities of stairs in comparison to horizontal routes. With measurements providing high resolution in time and space we found indications that the transition from the plane to the stair is responsible for the congestions and not the smaller capacities of stairs. A clarification of this question could improve the conduct of stairs and thus the design of emergency routes.

In this contribution an overview about the fundamental diagram for stairs is given. First we discuss discrepancies of fundamental diagrams of well-known handbooks for planning of pedestrian facilities and evacuation routes like Predtechenskii and Milinskii [1], Nelson and Mowrer [2], Fruin [3], and Weidmann [4]. To test the correspondence to real measurements, we collect published measurements available in literature [6-11]. In the second part we derive a fundamental diagram for stairs downwards based on own experiments and precise trajectories. To check whether the results of experiments performed under laboratory conditions are comparable with characteristics of motion of everyday situations, we present a comparison with results of a field study carried out at the same staircase [5]. Furthermore this contribution shows a method to gain topographical information of density, velocity, and specific flow structures to get a microscopic insight into pedestrian dynamics on stairs.

REFERENCES

- [1] V. M. Predtechenskii and A. I. Milinskii, *Planning for Foot Traffic Flow in Buildings*. Amerind Publishing, New Dehli, 1978, translation of: *Proekttirovanie Zhdanii s Uchetom Organizatsii Dvizheniya Lyuddskikh Potokov*, Stroiizdat Publishers, Moscow, 1969.
- [2] H. E. Nelson and F. W. Mowrer, "Emergency Movement," in *SFPE Handbook of Fire Protection Engineering*, 3rd ed., P. J. DiNunno, Ed. Quincy MA: National Fire Protection Association, 2002, ch. 14, pp. 367–380.
- [3] J. J. Fruin, *Pedestrian Planning and Design*. Elevator World, New York, 1971
- [4] U. Weidmann, "Transporttechnik der Fussgänger," Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau, ETH Zürich, Tech. Rep. Schriftenreihe des IVT Nr. 90, 1993, zweite, ergänzte Auflage.
- [5] S. Burghardt, A. Seyfried, and W. Klingsch, "Improving Egress Design through Measurement and Correct Interpretation of the Fundamental Diagram for Stairs," in *Developments in Road Transportation*, M. Panda and U. Chattaraj, Eds., *Proceedings of the International Conference on Developments in Road Transportation*, October 8-12, 2010, NIT Rourkela, Odisha, India. Macmillian Publishes India Ltd, 2010, pp. 181–187.
- [6] X. Chen, J. Ye, and N. Jian, "Relationships and characteristics of pedestrian traffic flow in confined passageways," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2198, pp. 32–40, 2010, doi: 10.3141/2198-05.
- [7] H. Frantzich, "A model for performance-based design of escape routes," Department of Fire Safety Engineering, Lund Institute of Technology, Tech. Rep. 1011, 1994.
- [8] Frantzich, H., "Study of movement on stairs during evacuation using video analysing techniques," Department of Fire Safety Engineering, Lund Institute of Technology, Tech. Rep., 1996.
- [9] M. Müller, "Fundamentaldiagramme von Personenströmen auf Tribünentreppen - Vergleich unterschiedlicher Steigungen am Beispiel der ESPRIT arena," Bachelor Thesis, Bergische Universität Wuppertal, 2010.
- [10] D. B. N. Seer, S. Bauer and M. Ray, "Estimating Pedestrian Movement Characteristics for Crowd Control at Public Transport Facilities," in *11th International IEEE Conference on Intelligent Transport Systems*, Oct 2008.
- [11] J. Ye, X. Chen, C. Yang, and J. Wu, "Walking behavior and pedestrian flow characteristics for different types of walking facilities," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2048, pp. 43–51, 2008, doi: 10.3141/2048-06.

A data-driven model of pedestrian following and emergent crowd behavior

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Can the collective behavior of human crowds be explained as an emergent property of local pedestrian interactions? To address this question, we have adopted a bottom-up approach motivated by cognitive science and grounded in experimental data. We utilize the behavioral dynamics framework (Warren 2006), which integrates an information-based approach to perception (Gibson 1979) with a dynamical systems approach to action (Kugler & Turvey 1987; Kelso 1995). A full understanding of behavior in this framework consists in specifying how information about the environment is picked up by the agent and used to control action (a control law), and a low-dimensional description of the global behavior that arises as a result (a behavioral strategy). We use experimental data on human locomotion to inform and test hypotheses about these processes, and to generate models of pedestrian behavior (Fajen & Warren 2003; 2007).

This paper applies our approach to the case of pedestrian following. One person following another is a common behavior in everyday life, and may provide a key link to the dynamics of crowd behavior. Successful followers must control their speed to stay behind the leader, and control their heading to stay on course with the leader. Here we focus on speed control. Our goal is to model the behavioral strategy and the visual control law governing following in dyads, and then use this model to simulate the emergent behavior of small crowds.

In Experiment 1 (with Chris Rhea and Jon Cohen), we investigated the behavioral strategy governing following. We collected data from pairs of pedestrians, who walked on a straight path in a 12 x 12 m room while their head positions and orientations were recorded using an inertial/ultrasonic tracking system (IS-900, 60 Hz). The 'leader' (an experimenter) walked 3 steps at a constant speed, then sped up, slowed down, or remained at the same speed for several steps (3, 4, or 5), and finally returned to the original speed. The 'follower' (a participant) began 1 or 3 m behind the leader and was instructed to follow him at a constant distance. We modeled the time series of the follower's acceleration using four candidates derived from the driving literature: (1) a speed model (Chandler, Herman, & Montroll 1958), based on matching the leader's speed; (2) a distance model (Pipes 1953; Herman, Montroll, Potts, & Rothery 1959), based on maintaining a constant distance behind the leader; (3) a ratio model of speed over distance (Gazis, Herman, & Rothery 1961), and (4) a weighted linear combination of speed and distance (Helly 1959; Andersen & Saur 2007). We used RMSE and Pearson's r to quantify goodness of fit. The results indicate that the speed model performed significantly better than the distance model, and the more complicated ratio and linear combination models did not further improve performance. We conclude that a simple speed-matching strategy is sufficient to account for pedestrian following.

In Experiment 2, our goal was to understand the visual information that is used to control following. The two most likely sources of information (Rushton & Wann 1999) are visual angle, the angle that the leader subtends at the follower's eye, and binocular disparity, the difference between the image of the leader in the follower's left and right eye. We used virtual reality to dissociate these variables (Tarr & Warren 2002), and independently manipulated the visual angle and binocular disparity of a virtual 'leader.' Participants followed a virtual target pole (1.65 m height, 0.5 m diameter) viewed in a stereoscopic head-mounted display (SR-80A, 63° H x 53° V) while they walked in a 12 x 12 m room. Head position and orientation were tracked (IS-900, 60 Hz) and used to update the display. A change in target speed over a 3 s interval was specified by (a) a change in visual angle, produced by expanding or shrinking the pole, (b) a change in disparity, produced by increasing or decreasing the pole's simulated distance from the follower, or (c) a change in both visual angle and disparity. These conditions were fully crossed, so that the changes could be congruent or incongruent. Participants' mean speed during the manipulation showed that they relied entirely on the change in visual angle ($p < .001$) and were not affected by the change in disparity ($p > .05$). We conclude that change in the leader's visual angle is sufficient to control speed in one-dimensional following.

We can combine these results to derive a control law that implements the behavioral speed-matching strategy. In effect, followers accelerate to null changes in the visual angle of the leader. This is more cognitively plausible than the speed-matching strategy, because there is evidence that human agents do not accurately perceive object speed (Rushton & Duke 2009).

Armed with this control law for pedestrian dyads, can we use it to scale up to crowds? In Experiment 3, our goal was to apply the control law for one-dimensional following to study small crowds. We collected data from four pedestrians steering toward a common goal. Participants began in a square configuration of variable size (0.5, 1.0, 1.5, or 2.5 m sides). After starting to walk, they were directed toward one of three goals located 8 m away. In a previous study (Bonneaud, Rio, Chevaillier, & Warren 2011), we found that these pedestrians coordinated their behavior by adopting a common speed. We hypothesized that the speed that emerges is driven by pedestrians in the back following those in front. Using the control law derived from Experiments 1 and 2, we predicted the time-series of the follower's acceleration as a function of the leader's visual angle, and used it to simulate group behavior. Thus, Experiment 3 demonstrates how a simple control law governing local pedestrian interactions may contribute to the emergent behavior of crowds.

In sum, we have used the behavioral dynamics framework to develop a cognitively-plausible, experimentally-grounded model of pedestrian following, which helps to explain the collective behavior of small crowds. This a powerful and underutilized approach that can enhance pedestrian modeling and inform future work on crowd dynamics.

REFERENCES

Andersen, G. J., and Sauer, C. W. (2007). *Optical information for car following: The driving by visual angle (DVA) model. Human Factors: The Journal of the Human Factors and Ergonomics Society*, 49(5), 878-896.

Bonneaud, S., Rio, K., Chevaillier, P., and Warren, W. H. (2011). *Accounting for patterns of collective behavior in crowd locomotor dynamics for realistic simulations. In Proceedings of the 2011 International Conference on Computer Animation and Social Agents.*

Chandler, R. E., Herman, R., and Montroll, E. W. (1958). *Traffic dynamics: Studies in car following*. *Operations Research*, 6(2), 165-184.

Fajen, B. R., and Warren, W. H. (2003). *Behavioral dynamics of steering, obstacle avoidance, and route selection*. *Journal of Experimental Psychology: Human Perception and Performance*, 29(2), 343-362.

Fajen, B. R., and Warren, W. H. (2007). *Behavioral dynamics of intercepting a moving target*. *Experimental Brain Research*, 180(2), 303-19.

Gazis, D. C., Herman, R., and Rothery, R. W. (1961). *Nonlinear follow-the-leader models of traffic flow*. *Operations Research*, 9(4), 545-567.

Gibson, J. (1986). *The Ecological Approach to Visual Perception*. New York, NY: Psychology Press.

Helly, W. (1959). *Simulation of bottlenecks in single lane traffic flow*. In *Proceedings of the Symposium on Theory of Traffic Flow., Research Laboratories, General Motors* (pp. 207-238). New York, NY: Elsevier.

Herman, R., Montroll, E. W., Potts, R. B., Rothery, R. W., Herman, R., Montroll, E. W., and Potts, R. B. (1959). *Traffic dynamics: Analysis of stability in car following*. *Operations Research*, 7(1), 86-106.

Kelso, S. (1995). *Dynamic Patterns: The Self-Organization of Brain and Behavior (Complex Adaptive Systems)*. Cambridge, MA: The MIT Press.

Kugler, P. N., and Turvey, M. T. (1987). *Information, Natural Law, and the Self-Assembly of Rhythmic Movement: Resources for Ecological Psychology*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pipes, L. A. (1953). *An operational analysis of traffic dynamics*. *Journal of Applied Physics*, 24(3), 274.

Rushton, S. K., and Wann, J. P. (1999). *Weighted combination of size and disparity: A computational model for timing a ball catch*. *Nature Neuroscience*, 2(2), 186-90.

Rushton, S. K., and Duke, P. A. (2009). *Observers cannot accurately estimate the speed of an approaching object in flight*. *Vision Research*, 49(15), 1919-28.

Tarr, M. J., and Warren, W. H. (2002). *Virtual reality in behavioral neuroscience and beyond*. *Nature Neuroscience*, 5, 1089-92.

Warren, W. H. (2006). *The dynamics of perception and action*. *Psychological Review*, 113(2), 358-89.

Comparison of different calibration techniques on simulated data

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The social force model [1] has developed into one of the main approaches for modeling and simulating pedestrian movement on a microscopic level. The model is defined by describing the acceleration of an individual pedestrian based on the sum of different attraction and repulsive forces: while an attraction force accelerates pedestrians towards their desired direction and speed, repulsion forces allow evasion from other pedestrians and boundaries.

Many papers (e.g. [2], [3], [4]) discuss model developments and calibrate these models usually using a single calibration method (with the exception of [4] where three methodologies are compared) based on pedestrian movement observations. However, it is not known what influence the choice of a specific calibration technique has on the quality of the calibrated model parameters. In particular, when calibrating pedestrian movement simulation models (PMSM), one has the problem that data collected with automated tracking methods as well as manually annotation is noisy due to inaccuracies of both methodologies. Additionally, most data collection methods deliver trajectories based on the head of pedestrians which includes body sway caused by the side movement of the pedestrian's head during each step. This introduces significant uncertainties as the positions and velocities of the surrounding pedestrians are used to model the acceleration of a pedestrian. Adding to this is the fact that the velocity and acceleration are calculated by differencing the noisy position data leading to increased errors for those variables. When using a maximum-likelihood estimation to estimate the model parameters directly from the observed acceleration data, this might lead to error-in-variables problems, resulting in a bias towards zero in the parameters (see e.g. [4]).

To give researchers a guideline when calibrating PMSM, this paper tests several calibration techniques. Therefore, we created a calibration dataset which originates from simulations instead of observation allowing full control over the real parameters that were estimated with the different methodologies. A corridor of 2 m width with bidirectional flows was chosen. Overall 50 pedestrians were simulated, 25 in each direction. The two groups were placed 10 meters apart into regular 4 x 7 grids. A position and goal in opposite grids were assigned randomly to each pedestrian out of the 28 grid squares. All pedestrians were assigned desired velocities from a normal distribution (mean 1.3 m/s, variance 0.2). Five scenarios were created. The elliptical model 2 from [2] was chosen for both repulsion from walls and pedestrians to create our calibration data set. To create more realistic data, a normally distributed error term with mean 0 and a high variance of 0.2 was added to each spatial position of the simulated data.

For our tests the parameters governing the interaction distance and the strength of the repulsive force between pedestrians were calibrated. Three different calibration techniques were compared on the

different data sets. The base method was a maximum likelihood estimation of the parameters directly derived from the calculated accelerations at each point in time. Other methodologies fit the simulated to the original trajectories. Two variants were compared both using the mean Euclidean distance between simulated and original trajectory as optimization criteria: first, all pedestrians were simulated at the same time, second, in each simulation run only one pedestrian was simulated and all remaining pedestrians were kept on their original trajectories. In all cases the desired velocities of pedestrians were calculated as the 90% quantile of the velocities in their original trajectories. Two different MATLAB optimization algorithms were used for parameter estimation: the first function applied was `fminsearch`, which uses a Nelder-Mead optimization algorithm. Here, the starting parameters for the optimization were also varied ranging from (a) the parameter values originally used to create the calibration dataset, (b) random start values. The second method was a genetic algorithm (GA) using the function `ga`, starting with a random population of 40. As the methodology does not rely on parameters found in real pedestrian behavior the parameter values were chosen using hints from literature and visual testing of the simulation.

The results show that maximum likelihood estimation might be feasible if small errors can be guaranteed in the input data. Otherwise, the error in variable problem will result in parameters with a bias towards zero. Further, the calibration using the Nelder-Mead algorithm is strongly dependent on the starting values as the algorithm tends to only find local optima. The GA does not suffer from a starting value problem as it incorporates random changes to the parameter values. However, due to the random search the estimated parameters vary to a much larger extent if the search space cannot be restricted at all. Compared to the parameter values of 20 and 0.17 for strength and interaction distance of the original dataset, the means from the GA estimation were 7.3 and 0.35 with standard deviations of 9.8 and 0.35. Using the optimal solutions of the GA as starting values for the Nelder-Mead algorithm improves the mean values to 12.3 and 0.17.

It can be seen from our results that a larger strength parameter results in a smaller interaction distance. This could be a sign for an identification problem for both parameters leading to a region of similar values for the objective function (see also [2]). This might be dealt with by using simulation data with different pedestrian densities as suggested in [4]. The same happens when the error in the data is large. The difference here is that the strength parameter tends to be estimated much too large and the interaction distance tends to be too small. A likely reason is that random error leads to very strong observed accelerations. When looking at the question of simulating all or only one pedestrian, the picture is not quite as clear. For small or no errors in the input data, simulating all pedestrians at once gives more stable and better parameter estimates. For large errors the parameter sets are both showing large variation but simulating one pedestrian at a time leads to more stable estimates.

In conclusion, the combination of a genetic algorithm followed by a numeric optimization step seems to be most promising. However, a test with more simulated scenarios and different densities is needed to verify the identifiability of the parameters. Together with these points, in future work, influences of inherent problems like body sway need to be included into the simulated data to test the methodologies further. Also other optimization criteria like walking time in the simulation versus the real walking time should be tested and possibly combined with the trajectory distance.

REFERENCES

- [1] D. Helbing and P. Molnar. *Social force model for pedestrian dynamics*, *Physical Review E*, 51 (5), 1995, pp. 4282-4286.
- [2] A. Johansson, D. Helbing and K. Shukla. *Specification of a Microscopic Pedestrian Model by Evolutionary Adjustment to Video Tracking Data*, *Advances in Complex Systems*, 10 (2), 2007, pp. 271-288.
- [3] S. Hoogendoorn and W. Daamen. *Microscopic Parameter Identification of Pedestrian Models and Implications for Pedestrian Flow Modeling*, *Transportation Research Record*, 1982, 2006, pp. 57-64.
- [4] C. Rudloff, T. Matyus, D. Bauer and S. Seer. *Can walking behavior be predicted? An analysis of the calibration and fit of pedestrian models*, to appear in *Transportation Research Records*.

Individual assessment of conflict prediction and group dynamic behavior as main driver for pedestrian dynamics

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Models for pedestrian dynamics cope with different aspects of behavior related to human movements. Generally, such models can be assigned to three different levels of movement characteristics: operational, tactical and strategic behavior. The basic microscopic models (e.g. social force, cellular automat, or discrete choice) particularly focus on the operational level (spatial exclusion or distance and direction related repulsion). Especially, the favorable social force approach, which states attraction and repulsion forces between the human beings, turns out as a good analogy to reproduce substantial self-organization effects. Several model modifications and extensions of the social force model have been recently developed by the scientific community. One can notice that sustainable concepts (e.g. discretization, floor fields) will be transferred between the different model approaches, and that the models will converge as an evolutionary consequence.

Instead of refining the standard ideas of movement modeling our current research projects lay emphasis on the pedestrian perception and cope with both the dynamic group behavior and the individual evaluation of potential conflict situations, and hence, rather focus on the tactical level of movement behaviour. Whereas models mentioned above primary consider operational aspects (spatial exclusion or distance and direction related repulsion), the consideration of psychophysical concepts, like our approach of regarding the perceived time-to-conflict, overcomes the idea of unspecific directed repulsion forces and derives specific movement decision with respect to the individual evaluation of potential conflict situations. The idea of considering the individual human perception to cope with enhanced patterns of movement behavior is from our point of view the next challenge for the upcoming research tasks. An interdisciplinary research approach including the research areas of traffic sciences, sociology, mathematics, physics and psychology will ensure that our proposed methods follows a common agreement of all parties involved.

The data recording to validate our developed fundamental methodology consists of three sources: (a) acquisition of data in the field, (b) isolated test environments for step wise parameter evaluation, and (c) complex test scenario to cope with the individual and complex interactions.

(a) For the data acquisition in the field, we recorded the movement behavior of the participants of the German Protestant Kirchentag at Dresden (1.-5. June 2011 with 120.000 fulltime participants and approx. 50.000 guests) and use this data as a solid base for the group constellation and behavior. As our data points out, there are significant differences in the density-speed-relation (fundamental diagram) regarding the constellation of groups. Heterogeneous groups consists of independent pedestrians possess a homogenous density and each pedestrian has a high flexibility to change the speed and the direction of motion. The effect of “clustered density” (local density spots) increases with the amount of

groups, their mobility, and with the group size. These density spots significantly change the individual speed characteristic and the corresponding avoiding behavior. Obviously, each group member plans the individual and group movements respecting the overall group benefit and consider the Pareto rule to ensure a common movement agreement. Due to the fact that this planning procedure often based on non-verbal communication, this procedure will fail with increasing density. Groups with a clear leader and follower structure as well as experienced groups contain of members with a comparable hierarchy status will efficiently solve this “synchronized” movement task even under crowded situations. We observed this movement patterns over a wide area, which lead in a higher variance of speed inside the pedestrian flow compared to the expected standard distributions. Highly agile groups are benefit from the density clusters by efficiently use of the corresponding free accessible space. So it seemed that a mixture of two different flows exits inside the pedestrian stream. These structures are stable in an environment up to 1.5-2 persons/m², but above this density tactical movements are barely manageable and the two separated flows are combined to one. We strongly suppose, that the ongoing data evaluation will provide further facts to approve these findings.

(b) The isolated test environment focuses on the individual assessment of conflict prediction, where our model concentrates on a time-to-conflict method. Model parameters are the different perception areas, the point of view (angle) depended perception of speed and path deviations. A comparison among the movement components speed and path deviation shows that the path deviation can easily be estimated if the traffic is oncoming but the corresponding speed is much harder to predict. Conversely, in the case of an orthogonally approximation, this effects transpose. With regard to the environmental perception, the individual characteristics (e.g. physics or assertiveness), and the group constellation we investigated different conflict avoidance strategies. A preliminary evaluation of the records points out a clear domination of just a few avoidance patterns. Considering this promising results, we will setup continuative test environments to prove these findings.

(c) Also to cope with the psychological interactions between human beings the results of evacuation experiments are included in our pedestrian model approach. In evacuation experiments, we observed again the existence of heterogeneous groups in terms of movement parameters. The results suggest that - even in situations which are characterized by high degrees of uncertainty and urgency - individuals more likely use social cues from the immediate surrounding social environment for their individual movement decisions. Obviously, such social cues reduce the uncertainty in critical situations and support decision making when own decision rules are not or only limited available. Hence, pre-existing group affiliation determines tactical decisions on an individual level and leads to “clustered density” on cumulative (collective) level (from a macroscopic point of view). Further in-depth analyses focusing on personality traits and movement related decisions indicated that certain traits (such as extraversion) are associated to the extent individuals use social information. These preliminary findings of group dynamics underline the need for considering characteristics of decision making processes (with respect to social interactions and on individual level), and thus, to focus on the tactical component within our comprehensive pedestrian modeling approach.

Evening presentation

Wednesday, 6 June - 20.00

Thomas Brudermann, Universität Graz, Graz AUSTRIA

Mass psychology revisited - Insights from social psychology, neuroscience and simulation

This talk revisits the classical field of mass psychology (also referred to as “crowd psychology”). Starting with an overview on related concepts from social psychology it discusses phenomena, where mass psychology plays a vital role: Human panics and stampedes, but also stock market bubbles, fashion trends or political movements. Although of different nature, phenomena driven by mass psychology have a common ground: Individual decision making is replaced by psychological contagion, and facts are replaced by opinions about facts. In further consequence contagion cascades might appear, causing irrational and hardly predictable collective outcomes.

Technological and methodological progresses in recent years advance the understanding for such mass dynamics. In particular, neurosciences on the one hand and agent-based simulations on the other hand are of great value: While neurosciences allow for a better understanding of human behavior on the individual level, agent-based simulations close the analytic gap between individual decisions and collective outcomes. A combination of insights from both fields hence contributes to a better understanding of mass dynamics.

Keynote

Thursday, 7 June - 09.00

Paul I. Weinmann, ICTS Europe, Amsterdam NETHERLANDS

Behavior assessment of individuals in crowds - a view from the perspective of aviation and airport security

International terrorism has long been a significant threat factor for the travel industry, pervading many aspects of mass transportation worldwide and generating dynamic developments in transportation security.

Civil aviation in particular remains one of the most attractive targets for terrorism, and the upcoming Olympic Games in London raise the threat level significantly. According to intelligence and evidence publicized recently in the media, terrorists are relentless in devising new *modi operandi* and improved techniques for concealing weapons and explosive materials, aimed at outwitting security technologies and bypassing security processes at airports. Their targets are airplanes, crowds of people at airports, and other airport facilities. Investment in the creation of multi-tier airport security systems, in research, and in the development of sophisticated security technologies has improved civil aviation security, especially since the events of 9/11. Nevertheless, as terrorist methods become more sophisticated, technology alone is limited in its ability to detect novel means of attack. Also, the technological approach to security engenders more and more security layers, increasing the already contested hassle to passengers and other airport users.

The security methodology briefly illustrated in the present lecture aims first and foremost at detecting the terrorist intent of individuals, rather than weapons and explosive material. During the whole course of information-gathering on potential targets, planning, and up until the very moment of attack, terrorists will try to disguise their real identities and intents by using false IDs and other documentation, pretending to have innocent aims (i.e., being regular passengers), and by camouflaging their dangerous tools. Such attempts to deceive security staff result, however, in patterns of appearance and behavior and in other indications that could suggest terrorist intent. Trained security staff familiar with such indications, which are also known as “suspicious signs” (as opposed to incriminating, “hard” evidence) are able to detect and evaluate these signs in real time, by applying moderate, polite, privacy-minded means such as verbal interaction, interview, and occasionally inspection of supporting documentation and data. The process will then result – if deemed necessary – in more discerning and appropriate security measures, thus complementing, or even compensating for, the shortcomings of security technologies.

This risk-based and pro-active methodology aims at optimizing the security process by identifying potentially high-risk individuals and focusing efforts on them. Such security layer needs to be implemented within the framework of standard processes and security procedures at airports, and it can also be integrated into other customary airport activities.

Oral presentations

Thursday, 7 June - 09.30

- A.13 *Rahul Jobanputra, University of Cape Town, Cape Town SOUTH AFRICA*
The development and calibration of an agent-based microsimulation model to simulate vehicle-pedestrian interaction
- A.14 *Heiko Aydt, Nanyang Technological University, Singapore SINGAPORE*
Symbiotic simulation for egress optimisation in smart buildings
- A.15 *Christoph Dobler, Eidgenössische Technische Hochschule, Zürich SWITZERLAND*
Integration of a microscopic force-based 2D pedestrian simulation into a framework for large-scale transport systems simulation
- B.13 *Helmut Schrom-Feiertag, AIT Austrian Institute of Technology, Wien AUSTRIA*
Simulation of handicapped people finding their way through transport infrastructures
- B.14 *Maria Davidich, Siemens AG, München GERMANY*
Calibration and validation of pedestrian simulations against real live scenarios based on video data: Example of a German railway station
- B.15 *Toshihiro Osaragi, Tokyo Institute of Technology, Tokyo JAPAN*
Simulation model of evacuation behavior following a large-scale earthquake that takes into account various attributes of residents and transient occupants
- C.13 *Julien Pettré, INRIA, Rennes FRANCE*
Velocity-based models for crowd simulation
- C.14 *Dorine Duives, Delft University of Technology, Delft NETHERLANDS*
Analysis of pedestrian self-organizing crowd movements at a music festival
- C.15 *Günter Bärwolff, Technische Universität Berlin, Berlin GERMANY*
Methods for modeling and simulation of multi-destination pedestrian crowds

The development and calibration of an agent-based microsimulation model to simulate vehicle-pedestrian interaction

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Marianne Vanderschuren, University of Cape Town, Cape Town SOUTH AFRICA

With the increases in computer processing power and advances in programming skills, an array of transportation and urban planning computer models are now available to the profession. They are extensively used in developed nations to model complex transport scenarios and interactions. Models vary from macroscopic, which focus on the system as a whole and a higher aggregation level, to more complex microscopic models, which allow the simulation of individual road users and behaviour to obtain more realistic representations at a local/street level.

The models, to varying degrees, give researchers and practitioners the ability to analyse the effectiveness of interventions on a disaggregated level, as individual vehicles and/or pedestrians are simulated in detail as they move through the road network with the goal of reaching their destination by the most cost effective or shortest route (Harney, 2002). Despite this, researchers indicate that, to date, the majority of microscopic traffic model development and simulation has essentially focused on the analysis of transportation efficiency, such as signalised intersections, arterial networks, freeway corridors and crowd evacuation or dynamics (Cunto, 2008).

The advances in technology have, however, led to the development of commercial microscopic models, which provide the opportunity to simulate vehicle and pedestrian interaction under varying infrastructure conditions. These types of models are gaining recognition as methods for assessing urban planning strategies as well as measuring and predicting safety and, offer the potential for proactive safety analysis for all road users rather than just vehicles.

Models simulate the interaction of road users via parameter settings of, for instance, compliance levels (i.e. attitude to risk), car-following distances, acceleration/deceleration speeds, walking speeds, aggression and awareness levels, etc. The values of these parameters are incorporated in the software at default levels set by the vendors and affect outcomes of modelled scenarios which may not replicate actual road user behaviour and thus current system performance. Calibration of these values is, therefore, vital to match observed conditions and to produce realistic outputs. Direct measurement of these values is very difficult because many of them represent subtle features that are hard to isolate and, because of the extensive amount of data collection required at a disaggregate level.

The complexity of microsimulation models and the large number of parameters that, usually, require specification means that the nature of calibration required is a complex and iterative process. Because of this, many researchers have reduced the number of parameters based on heuristics and on a trial and error basis. Additionally, the literature cites several studies with the primary goal of providing a robust calibration method. Early research work focussed on search algorithms for calibration based on

a single criterion. However, it is suggested that this approach fails to recognise that traffic is a multi-faceted entity (Duong, 2011). Multi-criteria calibration has been proposed as an improvement to this by a number of researchers (for example Toledo et al, 2004; Balakrishna et al, 2007); Ma et al, 2007; Ciuffo et al, 2008; Huang and Sun, 2009) but clearly depends on relative weighting of factors. Research is on-going into methods of removing any biasing of factors using this method.

This paper details the evaluation of parameters for a simulation study of a local arterial road in Cape Town, South Africa, using a commercially available package, Paramics. Results are compared to values obtained using default settings and parameters calibrated by using the methods described. The study indicates that, although the Agent-based version of this software allows flexible modelling of vehicles and pedestrians, and despite the calibration of the study network using methods described above, it does not allow the replication of observed local road user behaviour by vehicles and pedestrians at crossings. The modification of several of these behavioural parameters is possible in the software via a programmable module. Given the conclusion of the study, the investigation into the possibility of modifying appropriate parameters to replicate observed local road user behaviour is also presented.

REFERENCES

- Balakrishna, R., Antoniou, C., Ben-Akiva, M., Koutsopoulos, H.N., and Wen, Y. 2007. *Calibration of microscopic traffic simulation models. Transportation Research Record: No.1999, pp. 198–207.*
- Ciuffo, B.F., and Punzo, V., and Torrieri, V. 2008. *Comparison of simulation-based and model-based calibrations of traffic-flow microsimulation models. Transportation Research Record, No.2088, pp. 36-44.*
- Cunto, F. 2008. *Assessing Safety Performance of Transportation Systems using Microscopic Simulation. Thesis presented to the University of Waterloo, Canada.*
- Duong, D. 2011. *Calibration and validation of VISSIM microscopic traffic simulation model parameters using Pareto Archived Dynamically Dimensioned Search. PhD Student Paper, University Avenue West, Waterloo, Ontario.*
- Dowling, R., Skabardonis, A., Halkias, J., McHale, G., Zammit, G. 2004. *Guidelines for Calibration of Microsimulation Models. Journal of the Transportation Research Board, pp.1-10.*
- Harney, D. 2002. *Pedestrian modelling: Current methods and future directions. Road & Transport Research Dec 2002.*
- Huang, W and Sun, J. 2009. *A NSGA-II based parameter calibration algorithm for traffic microsimulation model. Proceedings of the IEEE Computer Society: 2009 International Conference on Measuring Technology and Mechatronics Automation.*
- Toledo, T., Ben-Akiva, M., Darda, D., Jha, M., Koutsopoulos, H. 2004. *Calibration of Microscopic Simulation Models with Aggregate Data. Transportation Research Record, No. 1876, pp.10-19.*

Symbiotic simulation for egress optimisation in smart buildings

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Increasing population and the trend of urbanisation results in more and more densely populated cities. Managing the increasing number of people in cities efficiently has become priority for many city governments. While urbanisation has many advantages it comes with its own problems. Most (if not all) large cities have to deal with problems that are typical for their size and density such as traffic jams, for example. Smart traffic systems can help to alleviate the problems to some extent. Another consequence of increasing population density in cities are high-floor buildings (e.g., office towers, mega shopping malls, high-rise residential buildings) that provide shelter, office space, entertainment, and recreation for thousands of people. Although buildings have to satisfy certain safety standards by design, for example by featuring well-displayed emergency exits and well-located fire extinguishers, the large number of occupants may cause significant congestion in case of a necessary evacuation due to events such as fire.

Technology can help to make operations more efficient and egress is no exception. In fact, as we will show in this paper, egress is a good example where technology can make a positive difference. Buildings are typically equipped with floor plans that show emergency exits and evacuation routes to the nearest exit. While such a static guidance system can give people a general idea where they are currently located and where the nearest exit is, it cannot provide guidance that adapts dynamically to the current situation. In case of an emergency, a situation may become very dynamic for various reasons such as rapid spread of fire and smoke, congested evacuation routes, blocked exits, or even panic. The ability to capture information about a situation in real-time represents an important advantage that can help to make egress more efficient. Smart buildings can be equipped with various forms of sensors (e.g., smoke detectors, heat detectors, motion detectors) and actuators (e.g., electronic sign-boards) that can be utilized by a guidance system. This guidance system can use real-time sensor data to dynamically adapt to the current situation and provide useful information (e.g., direction to the nearest/safest exit) to the evacuees by means of various actuators.

Given information about the current situation in the building, the guidance system can compute the preferred route to an exit from any location in the building. There are a number of challenges that need to be considered and adequately addressed. One important issue, that we will address in our work, is concerned with the dynamics of an emergency situation. We are concerned with dynamics that arise from the rapid spread of fire and smoke as well as human crowd behaviour. In particular, crowd dynamics may lead to congestions and bottle-necks in certain parts of the building. Although, a reactive zero-lookahead guidance system can probably take into consideration the number of people in the various parts of the building as well as the current location of the fire(s) in order to determine an ideal route in order to avoid congestion, it lacks predictive capabilities. This can be a serious

disadvantage and may even exacerbate certain problems. In this paper, we propose a simulation-based guidance system in a smart building environment. This system makes use of high-fidelity simulations that enable it to predict how the emergency unfolds in the near-future. For this purpose, we will utilize ideas from the field of symbiotic simulation [1,2].

Symbiotic simulation is a paradigm in which a physical system and a simulation system are closely coupled by sensors and actuators. This relationship is often mutually beneficial. The simulation system benefits from real-time sensor data which makes it possible to perform high-fidelity simulations of the physical system. The physical system, on the other hand, benefits from the outcome of what-if analyses conducted by the simulation system. The purpose of such a what-if analysis depends on the application. Here, we describe a smart building application where the guidance system is based on a symbiotic simulation system. Therefore, in this particular application, the symbiotic simulation system is concerned with a decision making problem: which is the best evacuation path at a particular time in a specific part of the building? The symbiotic simulation system is capable of evaluating alternative routes (e.g., what-if scenarios) by means of simulation as the egress event progresses. The ability of a symbiotic simulation system to simulate many possible what-if scenarios, enable the guidance system to analyse various possible solutions and select the one which provides the best performance (in terms of evacuation time or safety, for example).

In this paper, we demonstrate the effectiveness of the symbiotic simulation-based approach through various experiments. The experiments highlight the situations in which a smart building, equipped with an active guidance system, can be most effective in helping people escape from a building. These experiments are performed using an agent-based crowd model. For the simulated building, we consider a typical multi-storey office building. More specifically, the building model is adapted from publicly available floor plans of the World Trade Center in Long Beach, California.

REFERENCES

[1] R. Fujimoto, D. Lunceford, E. Page, A. U. (editors), *Grand challenges for modeling and simulation: Dagstuhl report*, Tech. Rep. 350, Schloss Dagstuhl. Seminar No 02351 (August 2002).

[2] H. Aydt, S. J. Turner, W. Cai, M. Y. H. Low, *Symbiotic simulation systems: An extended definition motivated by symbiosis in Biology*, in: *Proceedings of the 22nd Workshop on Principles of Advanced and Distributed Simulation*, 2008, pp. 109–116.

Integration of a microscopic force-based 2D pedestrian simulation into a framework for large-scale transport systems simulation

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Transport simulation is an important research topic for many years. In general there are two different areas of transport simulations. On one hand, models have been developed for the simulation of large-scale scenarios with hundreds of thousands or even several million entities. On the other hand, there are models for smaller scenarios with some hundred or a few thousand entities. The former class of models usually deals with vehicular traffic, where a microscopic modeling of the physics is not needed and one, instead, can draw on simpler models known from the field of dynamic traffic assignment. The latter class of models usually deals with pedestrians, where the scenarios are often related to evacuation situations. In those scenarios a microscopic modeling of the underlying physics seems to be necessary. In recent years, the interest in multi-modal simulation models has increased significantly. In such models, various transport modes are simulated simultaneously, including the interactions between agents using different modes. Typical fields of application are, for example, studies on car sharing and public transport.

However, attempts to implement a multi-modal simulation have to solve the problem that the computational effort to simulate large-scale scenarios with a microscopic model is enormous. To overcome this problem, we present an approach, where the level of detail within a model can vary. By doing so, it is, for example, possible to model interactions between cars and pedestrians only at selected areas. To simulate the interaction between the transport participants, a microscopic modeling is needed. This calls for a multi-agent simulation, where every transport participant is represented by a software agent. In the simulation, agents make independent decisions. This can for example be route and destination choice (e.g. where to go shopping and which route to take to the shopping mall). The use of agents in a transport simulation allows to model the human behavior in a realistic manner.

This paper introduces a combination of both—macroscopic and microscopic—approaches, where the vehicular traffic is simulated with a so-called queue model while the pedestrian movement is simulated by a force-based model. The obvious scenarios for such an approach are situations where the agents are arriving at a location by one mode of transport and then switching to another mode of transport.

The main advantage of the queue model is its computational efficiency, which is a basal requirement for large-scale simulations. In this model, the transport system is transformed into a network of links and nodes. Each link (street segment) is represented as a FIFO (first-in first-out) queue. Every agent has to remain on the link for a certain time (free flow travel time). Each link has a specific outflow capacity, which corresponds to the flow capacity of the associated street segment. If at any time the outflow capacity is used up, no more agents can leave the link. Furthermore, each link has a specific storage capacity. If it is used up no more agents can enter the link.

In the force-based 2D simulation, the agents' high-level planning (i.e. route and destination choice) is performed on a graph representing the transport system, while the low level behavior (i.e. physical interaction between the participants) is simulated with a force-based model. In the force-based model the simulation entities are emitting repelling (other agents and obstacles) and attracting forces (goal locations). The force-based model itself is based on existing well established approaches.

A challenging task is to model the switch from one mode to another. This is particular complicated when the involved modes are simulated with different simulation models — i.e. switch from the queue model to the force-based model or vice versa. An example is an agent who arrives by car in a parking lot, simulated by the queue model, and then switches to a true 2D simulation model. The reason is that different models are simulating on different physical resolutions but nevertheless influencing each other.

The proposed approach is developed as an extension — which is based on [1] — to the MATSim framework. MATSim stands for Multi-Agent Transport Simulation and is widely used in the transport simulation community. The main field of application is the simulation of large-scale vehicular traffic. Balmer [2] gives a detailed description of the framework, its capabilities and its structure. MATSim's application to a large-scale Switzerland scenario (over 6 million agents simulated on a high resolution network with 1 million links) is presented by Meister et al. [3]. MATSim is also applied to other scenarios like large-scale pedestrian evacuation simulations or the simulation of air transport. However, so far all applications are based on the queue model.

The introduced multi-modal model is tested on a hypothetical scenario. In the scenario, the agents arrive at a metro station or parking area next to a shopping mall. After leaving the metro station, the agents have to cross a street before they enter the mall, go shopping and return back to the metro station. Once the agents are again at the metro station, they get on the next train. Agents arriving at the parking area can walk directly to the mall. However, the access road to the parking area crosses the footpath between the metro station and the shopping mall. In this scenario there are three different modes of transport. First, there are trains serving the metro station. Second, there are pedestrians moving from the metro station to the shopping mall. The pedestrians are simulated by the force-based 2D model. And third there is traffic on the access road to the parking area next to the shopping mall.

The novelty in this paper is the combination of simulation models of different scales. The proposed approach gives the opportunity to simulate large-scale scenarios, while staying highly resolved where needed and being more aggregated where possible.

REFERENCES

[1] G. Lämmel (2011) *Coupling force-based and graph-based models for multi-agent wayfinding in complex environments*, Working Paper, 11-20, VSP, TU Berlin, Berlin.

[2] Balmer, M. (2007) *Travel demand modeling for multi-agent traffic simulations: Algorithms and systems*, Ph.D. Thesis, ETH Zurich, Zurich, May 2007.

[3] Meister, K., M. Balmer, F. Ciari, A. Horni, M. Rieser, R. A. Waraich and K. W. Axhausen (2010) *Large-scale agent-based travel demand optimization applied to Switzerland, including mode choice*, paper presented at the 12th World Conference on Transportation Research, Lisbon, July 2010.

Simulation of handicapped people finding their way through transport infrastructures

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Public transport infrastructures must accommodate large number of passengers while taking into account specific needs of certain groups such as elderly or handicapped people. Their design needs to facilitate wayfinding for people unfamiliar with the infrastructure. Moreover, the layout must provide for sufficient space such that delays due to congestion are minimized.

Thus the design process is a nontrivial task which nowadays is supported by pedestrian simulations to predict passenger flows already in the planning stage. Current models do not integrate a detailed en-route route-choice model that implements orientation or navigation behavior but rather use shortest-path routing only applicable for people familiar with the infrastructure.

However, different groups have different needs for their routes and their orientation depending on their sensory and mobility impairments. At the first visit of an infrastructure depending on the signage already finding the elevator can become a challenging task, especially for people having reduced reception capabilities. These individuals need much longer for their orientation, and potentially temporarily block passage for the others, if the design of the infrastructure does not support their needs sufficiently.

Consequently this paper discusses a research effort put into enhancing existing simulation models by including models for the motion and orientation behavior of mobility impaired passengers like individuals with prams, wheelchair users, individuals with sensory impediments and people being unfamiliar with the infrastructure.

Here to gather information on group specific behaviour a comprehensive field experiments were made with 47 people. Eight groups of people were identified who may demonstrate mobility patterns clearly distinguishable from the general population: 70+ age, people with pram, visually impaired, blind, wheelchair users, mobility impaired, hearing impaired and deaf. The main research focus was to investigate differences in walking speed, patterns in gaining information from the environment, orientation and navigation.

The experiment took place at a major transit hub in Vienna, the "Bahnhof Nord". For each person in the experiment one out of two different scenarios with typical usage patterns and different levels of complexity was selected. The scenarios contain specific tasks such as buying a ticket and drink for the journey, locating timetable information, or using the restrooms in the station.

Empirical methods were combined in order to gain relevant qualitative and quantitative data on pedestrian behaviour. A detailed description can be found in [1]. To gather the experiment data an observation technique typically called “shadowing” was used, see e.g. [2]. Hereby an observer follows the observed individual recording the major directional changes using a special application on a tablet PC. Additionally the observed person carried a voice recorder to document the wayfinding process (“thinking aloud”). With the combination of these two methods it is possible to observe which guidance information was recognized at which positions inside the infrastructure.

The analysis of the experiment data, shown in this paper, have revealed on the one hand surprising similarities between very different groups, on the other hand extreme deviations within a single group, indicating that in some cases determinants other than disability play a more significant role for travel time and navigation behaviour. The spatial analysis of trajectory data revealed the main routes, deviations from these routes and clusters where people mainly stop. The analysis of the thinking aloud data related to the trajectory helped to identify elements of the guidance system that respondents used to navigate and pointed out typical areas for orientation in the infrastructure.

The main contribution of this paper is to propose a simulation model that represents the specific groups and behaviours. An agent based approach is used allowing the characteristics of individual pedestrians to be assigned and varied as required. The human motion on an operational level is modelled based on a social force model [3]. As a first approximation the basic social force equations are used for modelling pedestrian and wheelchair movements varying two parameters: 1) The desired speed of the agent on which the attractive force and 2) the horizontal body size on which the repulsive forces are depending.

On the tactical level the cognition of guidance systems is modelled and makes it possible to simulate agent navigation through an unknown infrastructure using the present signage. No routing graph has to be defined in advance, only the information obtained from the signage modelled in 3D is necessary. The main routing strategy is searching randomly in the absence of any information. Information is obtained from signage elements (signs, monitors) in a certain area in front of the signage element. The process of searching for information consists of two phases, first a signage element is identified and walked towards, subsequently at a smaller distance and a suitable angle towards the signage element the information provided is absorbed.

In the example of the train station “Vienna North” the monitors are the primary signage to gain information. After knowing the departure information looking for the way to the train platform is the next step. The train platforms are indicated using a sign conveying the platform number. The visibility depends on the agent’s vision capabilities or a high crowdedness respectively (especially for wheelchair drivers with a lower point of view can be modelled). A 3D environment including 3D models for the simulated agents gives the opportunity to calculate possibly seen sections from one viewpoint realistically.

Finally in order to demonstrate the functionality of the wayfinding algorithm different scenarios are discussed in this paper. Starting at the elevator into the main hall of the “Vienna North” train station a wheelchair driver has to get the train to “Stockerau”. All scenarios are based on the same tasks in predefined order: First go to the toilet, then buy the ticket, look for a monitor to get the departure information, go to the supermarket and finally, use the elevator up to the platform where the train is departing. The three scenarios differ in the level of crowdedness and the agent’s vision: 1) empty hall, full vision, 2) empty hall, half vision and 3) crowded hall, full vision. Each scenario showed different

routes compared to the shortest route as expected for 1) and similar longer routes but different deviations for 2) and 3). Especially for wheelchair users crowdedness has a significant impact. Crowds often occlude the signage or form obstacles leading to a higher rate of manoeuvre, longer routes and travel discomfort.

The proposed multi-agent based simulation model facilitates an agent to find autonomously its way through a building based on signage information only and makes it possible to evaluate the visibility of the guidance system for different groups. It can reveal areas with leaks of guidance information for people unfamiliar with the infrastructure, especially for elderly and handicapped people with reduced reception capabilities.

REFERENCES

- [1] V. Egger, H. Schrom-Feiertag, G. Telepak, and L. Ehrenstrasser, "Creating a Richer Data Source for 3D Pedestrian Flow Simulations in Public Transport," *Measuring Behaviour* 2010.
- [2] Bauer, D., Brändle, N., Seer, S., Ray, M., and Kitazawa, K., "Measurement of pedestrian movements - a comparative study on various existing systems," in *Pedestrian behaviour: Models, data collection and applications*, ed. H. Timmermans, Emerald Group Publishing, 2009, pp. 301-319.
- [3] D. Helbing and P. Molnar, "Social Force Model for Pedestrian Dynamics," *Physical Review E*, vol. 51, pp. 4282-4286, 1995.

Calibration and validation of pedestrian simulations against real live scenarios based on video data: Example of a German railway station

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When planning a building, or, for example, organizing a special event, it is of vital importance to minimize risks due to critical situations. It would be very useful if one could predict such a critical situation for a crowd. Here pedestrian stream simulations are very helpful. They simulate behaviour of a crowd and thus allow playing through different critical scenarios such as evacuations. However, a pedestrian stream simulation can only be useful if it is capable of reproducing real situations.

If one wants to use a certain simulator for a concrete application, the best way is to test the simulator beforehand by comparing simulation data to data that was extracted from live observations and stored. In most cases measurements from live data are not available and simulations are calibrated based on known literature data or laboratory experiments. The most widespread approach is to take a Gaussian distribution for the free-flow velocity and Weidmann's fundamental diagram for the flux-density relation [1]. Here, three questions occur: First, are these assumptions relevant for any real life scenarios? Second, is it enough to have this information to calibrate a simulation against a real life scenario? And if not, what other parameters are necessary to do it? Last but not least, how it is possible to determine the accuracy of a simulation? This work strives to answer these three questions.

In this work we demonstrate a methodology for adjustment of pedestrian simulations to live scenarios. We demonstrate this on the example of a German railway station. We show the methodology step by step, starting with gathering data with video cameras installed at a major German railway station, then conducting data analysis, then calibrating the simulation tool against the data from the live scenario and finally validating the simulation results.

We start with extracting data from videos: Several cameras were placed on a high ceiling on a major German railway station. The trajectories of pedestrians were extracted manually from 1,5 minutes videos using a tool that allows to „click“ positions on the video. As a result for each video we obtained around 400 trajectories of individual pedestrians in time and space. All trajectories within the examined area were analyzed. We eliminated only the trajectories that were distorted by distance or largely obscured from the camera for velocity distribution flow-density analysis. However, these trajectories were used for source-targets statistics and to obtain a schedule of appearance and disappearance of pedestrians from a source. The detailed analysis of velocities and flow-density distribution is conducted exclusively on the visible and undistorted parts of the trajectories to keep measurement errors small.

We extracted the following information from the videos to adapt our simulation tool to the real life scenario:

- The topology of the area of interest in two dimensions. This is direct input data.
- The positions of sources and targets within a scenario, that is, the locations where people come from and to where they go to. This is again direct input data.
- Statistical information on the distribution of trajectories between sources and targets. This guaranties that pedestrians will walk in the right directions.
- A schedule of pedestrian appearances and disappearances.
- The scenario specific distributions of free-flow velocities.
- Measured data from which the density-flow relationship (fundamental diagram) valid for the current scenario can be derived. Our observation is that it is very important to use the measured free-flow velocity distribution that is correct for a particular scenario.

We would like to stress that in some scenarios additional input, like the average size of pedestrians, may be necessary or at least beneficial.

The analysis of the data from our live scenario revealed significant differences to known literature data [1], which underlines the importance of scenario specific measurements. Pedestrians appear slower than a usually accepted value 1,34m/s, and they slow down faster than it is suggested in a Weidmann diagram.

We tested the success of our approach with the help of a pedestrian steam simulation obtained from a benchmark model based on a cellular automaton. Clearly, no exact match of every individual trajectory of every pedestrian can be expected, at least since we have a statistic of trajectories and every start of simulation will provide a slightly different picture. Therefore, no individual trajectories can be compared. We need an aggregated quantity instead. We pick the density of the crowd as it evolves with time in an area of observation. The density can not only be measured quite easily in both cases, but is also of immediate interest, because densities above a certain threshold would be an indicator for impending danger.

We compare density at different parts of the scenario. The density evolution in simulation reproduces the observed on a video well, apart from the fact that it sometimes slightly overestimates it. However, if the simulation is used as a planning help to avoid critical situations or as on-line tool for the prediction of crowd congestion a slight overestimate can be tolerated whereas underestimate of density is unacceptable.

Thus, we proposed an approach of adjustment simulation against a real life scenario. The proposed method was tested on a complex real life scenario -- a major German railway station during rush hours. The success of the proposed approach was shown by comparison of simulation with videos. The critical parameters for adjustments are discussed.

Simulation model of evacuation behavior following a large-scale earthquake that takes into account various attributes of residents and transient occupants

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INTRODUCTION

In order to construct a simulation model for evacuation-efforts following a severe earthquake, we consider not only the spatiotemporal distribution of occupants remaining in the city, but also of transient occupants, (i.e., people who are walking or otherwise in the process of using transportation in the city). The model takes into consideration the behavioral characteristics of a variety of populations, some of whom are constantly moving and some of which remain in a single location within the city. We have attempted to account for the influence both people whose movement paths stay within the city and those returning home (e.g., from an office) on the number and spatial distribution of refugees. These aspects have not been addressed in previous studies.

STUDY AREA AND ANALYTICAL DATA

The region employed in this research was the Setagaya Ward of Tokyo. Setagaya has areas that are densely crowded with wooden structures, and thus are very vulnerable to housing collapse and urban conflagration in the event of a devastating earthquake. In addition, many workers and students live in Setagaya and commute within the Tokyo region (i.e., they would be counted as transient occupants). Location data for the railway passengers, automobile users, and pedestrians were predicted employing the results of previous research together with the detailed data available on individual attributes based on person-trip survey data (PT data).

MODELING PROPERTY DAMAGE

In a model describing building-collapse, the probability of collapse can be estimated for each building unit based on its year of erection or its construction type. We used data on building heights and street widths to make a forecast of street blockage caused by building collapse. In a model describing fire spread, a model of the Tokyo Fire Dept. was employed, which can account for different modes of fire spread and different structural building types.

MODELING HUMAN BEHAVIORS

The typical series of human behaviors when an earthquake strikes were categorized and modeled. We modeled the behavior of occupants being at home, from the perspective of initial reactions, searching for routes, methods of evacuation (direct evacuation versus two-stage evacuation), walking in a crowd (walking speed), and activities while waiting. The behavior of transient occupants and occupants in facilities other than their own residences are also modeled by taking into account their characteristics.

EXECUTION OF THE SIMULATION MODEL

In order to examine the importance of accounting for the presence of transient occupants and persons returning home, we analyzed the variations in people input into the simulation for 3 specific cases: (1) the population consisting only of occupants remaining in the area, (2) that population plus transient occupants, and (3) that population plus transient occupants and persons returning home.

In case (2), the time-based changes in transient occupants strongly affect the number of refugees, specifically, including them increases the number of refugees, and in case (3), the number of refugees is greatly increased by the inclusion of persons returning home in the daytime, when there would be many persons returning home. Examining the results by age group, there is an increase in child refugees (5–12 years) in the morning and evening, but the elderly population (65 or more years) showed little variation. In contrast, refugees in the 13-to-64-year age group grew by about 20% during the 08:00-to-17:00 time frame. More specifically, the presence of transient occupants and persons returning home, which has previously been unaccounted for, may cause an approximately 20% increase in the number of refugees estimated for the peak hours period. This is an amount that cannot be ignored.

Next, we consider the number of refugees in evacuation areas. In cases (2) and (3), there appeared a large influx of refugee railway passengers at the evacuation areas around locations with high densities of railway lines. Previous investigations regarding the numbers and locations of evacuation areas have usually been based on the numbers of local residents, but in an urban area with a highly developed transportation network, it seems essential for the planning of evacuation areas to account for the presence of transient populations on railways and other traffic arteries, especially during the morning and evening rush hours.

The simulation was executed, accounting for all occupants (whether in buildings, transient, or on their way home), and the risks during evacuation to open areas were evaluated. The cases of two-stage evacuation and direct evacuation were compared. Since residents at home make up a majority of the refugees at night, the risk is greatly reduced by organizing a two-stage evacuation. During the day, however, many of the refugees, specifically occupants who are not home residents, would not comply with a two-stage evacuation.

SUMMARY AND CONCLUSION

A simulation model was constructed to describe human actions (waiting, returning home, and evacuating) after an earthquake, taking into account property damage. A numerical simulation of people's reactions after a disastrous earthquake in Setagaya Ward of Tokyo was employed to verify the importance of accounting for the presence of transient occupants and that of persons returning home, and the importance of combining such a model with one describing property damage. Our analysis has revealed that the presence of transient occupants and persons returning home, who have not formerly been included in disaster prevention planning, may add about 20% to the numbers of refugees during morning and evening peak periods, a quantity that cannot be ignored. Two-stage evacuations were also evaluated from the viewpoint of risks during evacuation to open areas. This indicated large variations in the numbers and attribute profiles of refugees, depending on the refuge location and the timing of the disaster.

Velocity-based models for crowd simulation

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Several fields paid a lot of attention to crowd simulation these last years. This particular interest resulted in numerous crowd simulation models of various natures. The computer graphics community has participated to this proliferation to answer its needs ranging from the production of movies to the development of video games. Actually, the motivations of the graphics community are not very far from the one of transports science:

- Realistic simulation is expected. The computer graphics is more interested in visual realism of results, and often refer to believability to avoid strictly evaluating simulation models and comparing them to reality. Nevertheless, reality remains a crucial reference and the graphics community starts comparing their simulation results with real measurements.

- Emergent collective phenomenon is strongly desired. The seminal work from Reynolds [4] on flocking behavior emerged from the graphics community. It was particularly interesting because Reynolds' model has ability to simulate the emergence of collective behaviors with visually impressive results. Again, graphics community is interested in simulating the emergence of realistic collective behavior. Simulation models developed in the graphics field start being accurately evaluated on this point, including by comparing simulations with measurements of real collective behaviors. The community also now contributes the effort in collecting data.

- Realism is expected both at the macroscopic and the microscopic levels because both scales contribute to the visual aspect of results: a close-up view of simulated crowds is enabled. Agent-based models are the most fitting this need for realism at different scales.

The main objective of this paper is to present several models proposed in the graphics field which can be of interest for transport science, and, whereas they are often formulated on common basis, to detail their subtle differences.

Agent-based model is often identified as a single class of approach to crowd simulation by itself. Actually, several subcategories of approaches should be distinguished and compared. Especially, we distinguish at least two subcategories: position-based model and velocity-based model. These two different types of models can be distinguished as follows. We denote q_i the state of the agent i . A position-based model formulates interactions between two agents i and j as a function $f(q_i, q_j)$ of their respective state, whereas a velocity based model is also based on the first time derivative of these states $f(q_i, q'_i, q_j, q'_j)$.

A typical example of position-based model is the well known social force model [5]: the interactions between agents are formulated as some repulsive forces which are modeled as functions of the relative positions of agents. Social forces model, or, more generally force-based models received a lot of attention and were widely studied. Their drawbacks are also well known. In particular, they fail reproducing realistic individual locomotion trajectories, because, at the local scale, they are based on unrealistic foundations: indeed, a pedestrian is not repulsed by anyone that would be close enough to him, and he may avoid someone at some distance when required.

Actually, our research team gathers expertise in human motion science and computer animation and focused on how do human do perform collision avoidance maneuvers. We studied pairwise collision avoidance (1 vs. 1 participant) and checked various hypothesis provided by models. We also studied more complex situations with groups of participants walking in various geometries. By using accurate optoelectronics motion capture systems to study their motion, we could deduce the basic motion laws as used by humans to perform a collision free locomotion. We deduced collision avoidance models, and, more precisely, chronologically proposed the Paris predictive model [1], a similar model with simplified formulation and calibration on experimental motion data [2], and a synthetic vision-based model [3].

The two first models share identical foundations. The velocity space is explored and decomposed into two major components: the admissible and non-admissible velocity spaces that respectively correspond to velocities that enable collision free motion or not. These two models however compute these two components in different ways:

- the Paris model [1] explores a delimited time-window and search for an optimal admissible velocity. Based on some simplification of the expression of relative motions, the model is able to merge together multiple interactions in an efficient way.
- the second one [2] is entirely based on the expression of relative velocity vectors and is not limited to a time window, but it takes into account uncertainty in motion perception (i.e., in the expression of velocity vectors) to reproduce realistic human behaviors. Especially, in order to reproduce the timing of an interaction, the model successively reproduces the observation phase, the reaction phase and the regulation phase of an interaction.

The two first model [1]and [2] work under the following hypothesis: interaction are combined together (when a pedestrian faces several interactions)by sorting them according to time-to-collision and merging the n-firsts by exploring the common solution space. The vision-based model [3] explores a radically new path. This model is based on the following assumptions:

- Human behave according to simplistic perception/action loops
- Human implicitly combine multiple interactions by their vision (as a 2D space where all the information is projected)
- Human process this complex stimulus by selecting most urgent situations

We propose to continue detailing the difference between these models along the extended version of the paper, add comparison with other models from the graphics field (e.g., RVO [6]), as well as providing more general perspectives on the future of velocity-based models.

REFERENCES

- [1] S. Paris, J. Pettré and S. Donikian. *Pedestrian Reactive Navigation for Crowd Simulation: a Predictive Approach*. *Computer Graphics Forum*, Vol. 26, N° 3, Eurographics'07 Conference Proceedings, p. 665-674, 2007.
- [2] Julien Pettré, Jan Ondřej, Anne-Hélène Olivier, Armel Crétual and Stéphane Donikian. *Experiment-based Modeling, Simulation and Validation of Interactions between Virtual Walkers*. *Proceedings of the 2009 ACM SIGGRAPH/Eurographics Symposium on Computer Animation (SCA'09)*, 2009.
- [3] Jan Ondřej, Julien Pettré, Anne-Hélène Olivier and Stéphane Donikian. *A Synthetic-Vision-Based Steering Approach for Crowd Simulation*. *SIGGRAPH ,10: ACM SIGGRAPH 2010 Papers*, 2010.
- [4] Craig W. Reynolds. *Flocks, herds and schools: A distributed behavioral model*. *SIGGRAPH Comput. Graph.* 21, 4 (August 1987), 25-34, 1987.
- [5] D. Helbing and P. Molnár. *Social force model for pedestrian dynamics*. *Physical Review E* 51, 4282-4286, 1995.
- [6] Stephen J. Guy, Jatin Chhugani, Sean Curtis, Pradeep Dubey, Ming C. Lin, and Dinesh Manocha, „PLEdestrians: A least-effort approach to crowd simulation,“ in *Proceedings of the 2010 ACM SIGGRAPH/Eurographics Symposium on Computer Animation, Madrid, Spain, July 2-4, 2010*, pp. 119-128.

Analysis of pedestrian self-organizing crowd movements at a music festival

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INTRODUCTION

Major pedestrian crowd movements have proven to be volatile in the past (e.g. Cambodia water festival 2010, Duisburg Love Parade 2010). Simulation by means of pedestrian models is used to predict possible hazardous locations and time intervals at major pedestrian crowd events and as such can help prevent pedestrian crowd accidents. The contribution of this research is to build on the current theoretical knowledge that qualitatively and quantitatively describes the transition effects between the self-organising regimes within pedestrian crowd movements. Using a to a UAV attached camera, footage of pedestrian crowd movements was recorded at a major music festival in the Netherlands. The visible crowd movements are analyzed using a completely new developed tracking tool, resulting in better definition of the transition between self-organisation regimes.

BACKGROUND AND LITERATURE REVIEW

Several scientists have tried to describe pedestrian crowd behaviour, with a focus on public space planning and design. Eventually various speed-density curves were extracted by means of experiments (Fruin 1987), (Predtetschenski 1971), observation of natural behaviour (Helbing 2005, Alghadi 2002) and the analysis of disasters. All of the above concluded that higher crowd densities reduce individual walking speeds. Fang et al. (Fang 2003) combined the work of Fruin, Predtechenskii and Milinskii and subtracted an upper and lower bound on the density-velocity graph, which clearly shows the lack of conformity between these attempts to define pedestrian crowd behaviour based on solely velocity and speed.

Additionally, several forms of self-organisation have been described in literature, e.g. bi-directional lane and stripe formation, zipper-effect at bottlenecks stop&go waves (Helbing, 2005), turbulent behaviour and pressure shockwaves in still-standing crowds (Helbing 2001). However, the exact relationship between the pedestrian flow characteristics (especially under high densities) and the forms of self-organising behaviour is poorly understood. This could be caused by the lack of stable and long time coverage of high-density pedestrian crowd movements.

Many tools have been used to make pedestrian tracking with respect to traffic flow experiments easier, such as coloured caps, white t-shirts, contrasting walls and floors and predefined limited areas of movement. However, these tools can only be used in stable research environments.

In this research three main questions will be answered. First of all, can our proposed observation technique be used to record and analyse pedestrian crowd movements? Secondly, can a new tool be developed that can detect and track multiple pedestrians from a reasonably big heights (50 – 100 m)

where no preliminary measures to facilitate identification are used? And last of all, can the transition between self-organising regimes be specified based on the macroscopic flow characteristics (speed, density and intensity)?

METHODOLOGY

With a new data collection tool - an octacopter, equipped with a lightweight high-speed high-definition camera with a F3.45 41.4 35 mm Leica lens - we are now able to film outdoor pedestrian crowd movements without interfering with the natural movement of the pedestrian crowd. Unlike most CCTV, an air borne camera records a top-view image from a height of 50 meters or higher, which ensures limited occlusion of pedestrians and a large recording area. Fig. 1.b displays the images recorded this year at a Dutch music festival named Lowlands. The total area covered by the camera is 500 by 350 meters and shot under an angle of approximately 49 degrees. On average 250 - 800 pedestrians are visible in every frame.

Vibration and interlacing and occlusion are present in the image sequences. Furthermore due to the relatively small dimensions of a singular pedestrian there is only limited information available on each pedestrian. Therefore a combination of the lens calibration and orthorectification procedure developed by the TU Delft, background tracking optical flow calculations and a colour mixture model was used to track each pedestrian in the crowd. Depending on the density of the flow this method can accurately account for the 80 - 90 percent of the pedestrian movements within the image.

After the data collection, the forms of self-organisation within the crowd are investigated based on the formation (physical location) of visitors within the crowd, the macroscopic flow variables speed, density and intensity and the microscopic variables spacing and angular deviations are used in the investigation. Optical flow calculations are used as an estimation of speed. Density is determined based on the number of pedestrians per surface area (5x5 meters). Counting the number of pedestrians crossing predetermined borders in two separate directions, intensity in two directions is calculated. Spacing between pedestrians is calculated using the distance between an individual and other pedestrians within the vision field. The last variable records the shift between the current direction and the following movement direction.

RESULTS

The recorded pedestrian movements are translated into time series of each of the above described variables. Additionally we were able to deduct individual trajectories from the recordings, which created the possibility to also deduce individual traffic characteristics (e.g. speed, angular deviation, headways and an OD-matrix). Besides the flow characteristics also the recorded self-organisation regimes were mapped within the sequences. Three predominant forms of self-organization are visible within the sequences, namely lane & stripe formation, stop & go waves, and the lack of both regimes (dominant flow in 1 direction). Because the found self-organisation forms have very distinct macroscopic flow characteristics, these characteristics can be used as an indication of the appearance of the self-organisation forms. The transition into the last regime gives an indication of the flow characteristics that determine self-organisation 'break-down'. It was found that particularly density, crowd speed and crowd formations play an important role during break-down. Whether the lack of self-organisation is solely caused by either one or by a combination of these three is still being investigated. It is expected that the final version of this paper will explain their role in the break-down process, or at least attempt to do so.

REFERENCES

Algadhi, S.A.H., H. Mahmassani, R. Herman. „A speed-concentration relation for bidirectional crowd movements.” In *Pedestrian and Evacuation Dynamics*, door S. Sharma Schreckenberg. M, 3-20. Springer, 2002.

Fang, Z., S.M. Lo and J.A. Lu. „On the relationship between crowd density and movement velocity.” *Fire Safety Journal*, 2003: Vol. 38, pp. 271 - 283.

Fruin, J. *Pedestrian - planning and design*. Mobile, Alabama: Elevator World, 1987.

Helbing, D., P. Molnár, I. Farkas, K. Bolay. „Self-Organizing pedestrian movement.” *Environment and Planning B: Planning and Design*, 2001: Vol. 28, pp. 361 - 383.

Helbing, Buzua, Johansson. „Self-Organized Pedestrian Crowd Dynamics: Experiments, Simulations and Design Solutions.” *Transportation Science*, 2005: Vol. 39, pp. 1-24.

Hoogendoorn, S.P., H.J. van Zuylen, M. Schreuder, B. Gorte, G. Vosselman. „Microscopic Traffic Data Collection by Remote Sensing.” *Transportation Research Board 2003 Annual Meeting*, 2003: pp. 1 - 11.

Predtetschenski, W.M., Milinski, A.I. *Personenströme in Gebäuden*. Berlin: Staatsverslag der Deutschen Demokratischen Republik, 1971.

Methods for modeling and simulation of multi-destination pedestrian crowds

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INTRODUCTION

Rapid growth in the volume of public transport and the need for its reasonable, efficient planning has made the description and modeling of transport and pedestrian behaviors an important research topic in the last twenty years. In the study of pedestrian behavior, evacuation scenarios (in which pedestrians all target a definite destination) and multi-agent systems (in which pedestrians are treated as heterogeneous individuals) have attracted much attention as two specific problems.

Comparatively little attention has been paid to the problem of pedestrian crowd behaviors in geometries with multiple destinations: each of the possibly many pedestrians moves to one out of a number of destinations. The objective of the present study is to investigate pedestrian behavior in such a context. The central problem is the modeling of crossing pedestrian streams. In view of a desirable practical relevance, realistic, i.e. rather complex geometries are studied in this context.

EXPERIMENTS

In order to obtain reliable empirical data of multi-directional, intersecting pedestrian flows for the evaluation of different simulation models, in 2010 we conducted human crowd experiments at the Technische Universität Berlin. One particular experimental setup, for example, arranged for two pedestrian flows (142 and 83 subjects) to intersect at an angle of 90 degrees for one minute in a region of about 25 square meters, resulting in peak densities of about four pedestrians per square meter.

The pedestrians' spatio-temporal positions were obtained via photogrammetric means from video data recorded with multiple temporally synchronized network surveillance video cameras. Tracking of the pedestrians was facilitated with the standard Lucas-Kanade algorithm. In our case, a particular challenge was presented by the fact that due to constructional limitations the scene could not be captured from a bird's eye view. Thus the effect of the pedestrians' different heights could not be assumed as negligible - and since the pedestrians' heights were not known beforehand, we needed to devise a method for extracting the pedestrians' positions reliably without this information. Smooth trajectories were then obtained via approximation with cubic B-splines, and the combinatorial assignment of trajectories obtained from different camera perspectives was supported with the Kuhn-Munkres algorithm. We then computed a local density field via nearest-neighbor kernel density estimation. Compared to the fixed bandwidth estimator commonly used in the literature, our approach yields a density field which provides spatially averaged values across mesoscopic regions that are more faithful to the standard method of counting pedestrians in that region.

We argue that the spatio-temporal density configuration as a representation of pedestrian dynamics is particularly suited for the calibration and validation of a variety of models: macroscopic simulations

already produce density fields, and data obtained from experiments or microscopic simulations may be easily converted.

SIMULATION MODELS

In the last years, several methodical approaches have been investigated for the modeling and the simulation of traffic problems. In the present context, it seems adequate to develop both microscopic approaches in which the pedestrian is considered as an individual interacting with other pedestrians, and macroscopic models in which pedestrian behavior is analyzed in terms of more global properties of a continuous stream. In the present project two microscopic models are developed. The first one is a grid-based approach rooted in cellular automata (CA) models. The second one is a combination of a force based and graph based approach.

In the traditional CA model and its various extensions, the state change of the cell (i.e. position) is applied to describe the system dynamics of the simulation. Due to this conceptual limit, to our knowledge, the simulation participants (i.e. pedestrians) are all associated with a fixed spacial size, defined by the size of the grid cell in the CA model. Consequently the pedestrians in the simulation have a fixed exclusive personal space which differs from empirical observations. In our model this exclusive personal space is given additional attention. The effect of a modifiable exclusive personal space is achieved by defining the inaccessibility of the surrounding cell position of an arbitrary pedestrian. By this means it is possible to describe simple group behaviors, i.e. pedestrians which belong to the same group may require a smaller exclusive personal space, while toward other pedestrians in the simulation environment, the nearby cell positions are declared as inaccessible and thus keep the latter at a relatively larger distance as what we would imagine in real-world situations. Our model also presents an advanced local step calculation to enable the so-called multi-cell-step, i.e. the transition from a start position to a destination with a distance larger than one grid cell. In the step calculation the execution sequence of the simulation participants is affected, in addition to the participant's own characteristics, by the actual system dynamics as well. This enables a substantial reduction of the "deadlock" phenomenon. This model is applied with some simple configurations with which the pedestrians are given pre-defined start positions and destinations. With the notion of the modifiable personal space, the simulation with advanced step calculation can be realized in combination with pedestrian density control, if necessary.

The combined force- and graph-based approach treats every participant as an agent, who makes her own decisions. While the graph is only needed to find a path from the origin to the desired destination, the agents' actual locomotion is driven by a force-based model. The model not only encompasses simple repelling and attracting forces but also more complex forces for explicit collision avoidance. The macroscopic approach is based on a set of pedestrian-specific coupled partial differential equations (PDEs) The equations are not derived from the Euler-/Navier-Stokes-PDEs known from fluid and gas dynamics. The specific situation of multi-destination pedestrian crowds with crossing streams requires the development of appropriately adapted methods. This has been targeted by the use of simple heuristics.

Typical applications of these approaches include real-world scenarios like airports, shopping malls, buildings of middle- to large size etc., where the participants (i.e. the pedestrians) do not exhibit an overall unanimity and (may) have different and multiple destinations. Beyond the modeling of the above-mentioned problems, a particular aim of this project will be the development, implementation and test of appropriate computer-based simulation models. The reliability of these models will be illustrated by a comparison with real data obtained from crossing pedestrian streams experiments.

Keynote

Thursday, 7 June - 14.00

Mehdi Moussaïd, University Paul Sabatier, Toulouse FRANCE

The modeling of human crowd behavior: Where physics meets cognitive science

Human crowds display a rich variety of self-organized behaviors, ranging from the spontaneous organization of traffic flows under everyday life conditions, to the emergence of crowd turbulence at extreme density. To understand the mechanisms underlying these phenomena, a reliable model of pedestrian behaviour is necessary. In this contribution, I will show that such a model lies at the crossroad between physics and cognitive science.

First, I will show that two simple cognitive rules based on visual information can describe the motion of pedestrians well. In particular, these two rules are sufficient to reproduce the self-organized properties of crowds observed below a certain density threshold. As the density of people increases, however, body contacts between neighboring people occur, and the underlying mechanisms change. During overcrowding, intentional avoidance behaviors are replaced by unintentional physical interactions, which can be described by using Newtonian repulsion forces.

Therefore, the large variety of crowd movements results from a density-dependant balance between physical effects and cognitive processes.

Oral presentations

Thursday, 7 June - 14.30

- A.16 *Ulrich Kemloh Wagoum, Forschungszentrum Jülich GmbH, Jülich GERMANY*
Empirical study and modelling of pedestrians' route choice in a complex facility
- A.17 *Piotr Tofilo, Main School of Fire Service, Warsaw POLAND*
Staircase evacuation with firefighters counter flow - experimental data and output from popular modeling software
- A.18 *Robert Zinke, Friedrich-Schiller-Universität Jena, Jena GERMANY*
Psychological aspects of human dynamics in underground evacuation: field experiments
- B.16 *Gregor Lämmel, Technische Universität Berlin, Berlin GERMANY*
Getting out of the way: collision avoiding pedestrian models compared to the real world
- B.17 *Ignacio Martínez, Ineco S.A., Madrid SPAIN*
Methodology for pedestrian simulation with complex/random routes in public spaces
- B.18 *Ladji Adiaviakoye, Groupe ESEO, Angers FRANCE*
Collection of data stemming from the fine trajectory of the pedestrians

Empirical study and modelling of pedestrians' route choice in a complex facility

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In recent years pedestrian dynamics has gained more importance and a lot of attention due to continuously growing urban population and cities combined with an increasing number of mass events. Major issues in this area include orientation and wayfinding. This is essential for reproducing route choice in computer models and is difficult due to the many underlying subjective influences on this choice. This paper presents an empirical analysis of pedestrians' route choice behaviour in a complex facility done within the framework of a real-time evacuation assistant [1]. This study is complemented by a modelling approach used to reproduce the observed phenomena.

The investigated facility is part of the promenade of the Esprit Arena in Düsseldorf, Germany. The route choice data are obtained from an automatic people counting system consisting of cameras. The cameras are optimally distributed at main entrances, exits, and passages of the promenade. This distribution leads to a logical partitioning of the area into 5 sections, which are mapped to the detection areas of the automatic people counting system. The counting system consists of 45 mono and 51 stereo cameras. Each camera is merely responsible for one exit, which means that at each time the information (in this case the number) about the pedestrians passing through that exit is available. Also, the passing direction for each exit is identified making it possible to know exactly how many pedestrians are inside a specific section. The data are presented in terms of frequencies, i.e. the number of persons passing the corresponding counting line or exit per minute in the direction 'in' and 'out' of a section. Using that information the proportional usage of the different exits of the promenade could be calculated. This has been done for different football matches and concerts. The results for two football matches played on the 5th and 18th August 2011 are presented and analyzed in this contribution.

The framework used for describing pedestrian traffic in this contribution is divided in a three-tier structure. One distinguishes between the strategic, the tactical and the operational level [2]. At the strategic level pedestrians choose their desired final destinations and a strategy to reach that destination. The strategies used here are the shortest paths (local and global) combined with a quickest path approach. Short-term decisions are taken at the tactical level, avoiding jams or switching to a faster route for instance. Basic rules for motions are defined at the operational level. These rules include accelerating, decelerating, and stopping.

The operational level is defined by the generalized centrifugal force model [3]. This model belongs to the group of force based models and operates in continuous space. Pedestrians are defined by ellipses with velocities dependent semi-axes.

The underlying routing model at the tactical is presented in [4]. It is a quickest path approach that operates on a navigation graph. The graph has been semi-automatically generated for the investigated part of the promenade. This has been done using the inter-visibility of exits. Some nodes have been manually inserted into the initial graph when for instance two exits in the same room were not visible from each other. After the graph is constructed, well established algorithms like Floyd–Warshall are used to compute the shortest paths to all possible final destinations. The information is stored in order to save computing resources. The nodes of the graph are navigation lines and the desired moving direction of pedestrians is always perpendicular to those lines. The visibility range of the pedestrians, which depends on their current positions, combined with an optimal queue selection is used for (re) direction. Once arrived in a new location, the pedestrians sense their environment and based on their perceptions, take decisions that minimize their travel time by systematically avoiding jams. This is on one hand achieved by analyzing the processing speed of different queues at exits and choosing the best suitable one. On the other hand pedestrians also try to escape from an already existing jam situation whenever possible. This is the case when a pedestrian is not constrained in the middle of a crowd for instance.

Preliminary results show that exits located at corners seem hidden and thus are not attractive for pedestrians, but these results need further investigations.

REFERENCES

- [1] S. Holl, A. Seyfried, *Hermes - an Evacuation Assistant for Mass Events*, in *SiDe* 7 (1) (2009) 60-61. URL http://inside.hlr.de/pdfs/inSiDE_spring2009.pdf
- [2] S. P. Hoogendoorn, P. Bovy, W. Daamen, *Microscopic Pedestrian Wayfinding and Dynamics Modelling*, in: M. Schreckenberg, S. Sharma (Eds.), *Pedestrian and Evacuation Dynamics*, 2002, pp. 123-155.
- [3] M. Chraïbi, U. Kemloh, A. Seyfried, A. Schadschneider, *Force-based models of pedestrian dynamics*, *Networks and Heterogeneous Media* 6 (3) (2011) 425-442. doi:10.3934/nhm.2011.6.425.
- [4] A. U. Kemloh Wagoum, A. Seyfried, *Optimizing the evacuation time of pedestrians in a graph-based navigation*, in: M. Panda, U. Charraraj (Eds.), *Developments in Road Transportation*, Macmillian Publishers India Ltd, 2010, pp. 188-196

Staircase evacuation with firefighters counter flow - experimental data and output from popular modeling software

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The counterflow condition on the escape stairs is a situation that may occur during the evacuation from buildings when the downward flow of evacuating occupants passes the upward flow of firefighters heading to the fire floor. It does not always take place because in majority of lower buildings evacuation starts and ends before fire brigade arrives on the scene. In case of taller buildings the conflict between the two movements is more likely to happen due to certain factors: the firefighting and evacuation strategy adopted for the building, the use and purpose of the building, the number of staircases and sizing of the stair, fire warning systems available, the quality of management and staff training, the availability of firefighters lifts and the distance to the fire station.

The evacuation strategy in taller buildings is usually either simultaneous or phased. In case of simultaneous evacuation the counterflow condition is more likely in case of long pre-movement times that are usually the result of inadequate warning systems or poor training. In this case the movements are more likely to coincide. An important issue here is the sizing of the stairs and the philosophy here varies slightly from country to country. For example in UK the sizing of the stairs for simultaneous evacuation is directly related to the whole number of occupants in the building which implies that the total number of people must have enough standing space within the staircase. In most countries however stairs are sized to the highest floor population based on assumption that floors are well compartmented and only the fire floor and the one above must be evacuated immediately while other floors will have more time. This concept is quite close to the phased evacuation which allows narrower stairs, however phased evacuation is usually gradual and controlled by warning system, internal communication, well trained staff and the fire control centre. In case of phased evacuation, due to a delayed evacuation of some floors, the likelihood and the impact of counterflow increases.

In British regulations (ADB) this is acknowledged by a requirement for checking whether the effect of fire fighters on phased evacuation is possible. This should be taken into account while deciding for the number of staircases in the building assuming that one may be discounted due to fire brigade activities. In practice the most likely occasions where counterflow is expected are tall offices, hotels and the buildings that are not tall enough to have firefighting lifts while having significant population. The problem of counterflow can be even bigger in cases where disabled people are evacuated.

The aim of this work is to study the effects of counterflow in connection with the requirements of regulations and most common evacuation strategies. The second aim is to provide data for numerical modeling and calculations. To achieve these goals a series of experiments was conducted on a staircase with and without a simultaneous counter flow of ascending firemen. Experiments took place in a typical representative staircase of an office building. The effect of the fire brigade intervention on

evacuation movement on stairs was examined for several different initial densities. 78 people were involved in the experiments – 73 as evacuees and 5 as firefighters. In every run the same number of students was involved but to simulate different floor densities, they were placed on different segments of the stair case. The lower floor density was applied the more levels of the staircase were occupied. The start of every run was signaled by a loud whistle audible for all people on the stair case. The evacuees were asked to move calmly and not to run downstairs. They were also asked to move all at once at the start of every run to keep the floor density from the beginning of the run to the moment when they meet firefighters.

For data collection a full measuring installation was prepared. It was composed of two IR directional sensors (one for every exit door) connected with the counting unit to the computer with software. The sensors were mounted on the top of both door openings and they were giving impulse to the counting unit any time when the person was passing the door in the outside direction. The sensors were calibrated to measure anybody who is at least 140 cm tall and they should recognize every person even in high floor density. The calculating unit was set up to give information to the computer about number of evacuated people in one second time steps. Additionally video cameras were used. One was placed on the first floor which was the best place to observe the influence of firefighters' movement on the evacuation process. The second video camera was used by one of the firefighters to record the fireman's perspective during the counter flow movement.

The results and discussion will be presented in a paper. A factor accounting for the counter flow is proposed for egress stair sizing calculations in cases where counter flow is identified as a potential problem. The experimental results are compared to simulations performed with current popular evacuation packages: EVAC, STEPS, Building EXODUS, Pathfinder. Various aspects of software application, necessary adjustments and the implications for evacuation studies in the context of fire safety will be discussed.

Psychological aspects of human dynamics in underground evacuation: field experiments

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For modelling pedestrian behaviour, especially in evacuation situations, a variety of simulations exists. They regard aspects like the environment or the type of event with varying intensity; some also consider social forces and human factors aspects (overview in Schadschneider et al., 2008). It has been claimed for some time now that human factors aspects or social behaviour should be integrated in simulation models (e.g. Sime, 1995). An example is the simulation of individual agents with different emotional states (e.g., Thiel-Clemen, 2010).

While simulation models have started to embrace a broad access to human factors, empirical data from laboratory experiments seem to concentrate on external aspects of pedestrian behaviour. These aspects include the relevance of the number of individual moving objects for the time needed for evacuation, and the consequences of walkway or driveway dimensions (e.g. Schreckenberg, 2010; Schadschneider et al., 2009). Also more general characteristics of pedestrian movement are investigated with evolving patterns and paths of movements in crowds underlying social forces (e.g. Moussaid et al. 2011; Helbing et al., 2000).

At the same time, literature calls for the inclusion of further human factors aspects into models of evacuation behaviour. For example, panic and irrational behaviour are in real events not found as often as expected (so, Tubbs & Meacham, 2007). Further aspects are distance keeping between pedestrians (Forell, 2004) and altruistic behaviour in evacuation scenarios (Dynes, 2006).

Only few field studies investigate these phenomena empirically; less do so in specific infrastructures like underground stations. Yet, only field studies can determine the incidence and relevance of human factors phenomena which the literature describes only in general. In order to identify observable human factors and to determine their effects, field experiments are the method of choice.

The research project OrGaMIRPLUS, funded by the German Ministry of Education and Research, deals with several aspects of human factors in evacuation of underground transportation systems. By specifically addressing social human factors aspects of pedestrian behaviour in the context of an underground subway station, it may contribute for further improving evacuation guidance and simulation models.

The overall aim is to improve evacuation of stations and to shorten the time needed for safe egress of passengers. Based on the findings from field experiments, observable human factors will be formalized according to their effects on the overall time needed for evacuation.

A preliminary study in an underground subway station included counts of passengers (e.g. how many passengers are handicapped, travel in company or groups). Structured interviews (n= 213) with passengers asked for knowledge about evacuation, warning signals, and interviewees' estimation

of their own behaviour in an underground evacuation. One result is a clear preference (67%) of not leaving without one's partner or children. Interviewees also said they wouldn't use an unfamiliar way out if instructed to do so.

Based on the results from the preliminary study and the aspects found in the literature, four series of field experiments were carried out in different underground train stations in Germany. The field experiments varied several infrastructural, individual and social variables. Group sizes varied between 30 and 130. Tasks included moving quickly along different distances on the platform, up and down turned off escalators and stairs, and egressing on tracks into the tunnel. Structured interviews were conducted after each single experiment. All tasks were video-recorded and later analysed for re-occurring social and human factors aspects. Participants were asked to comment on their own behaviour, the movement of the group, and how they experienced infrastructural specificities. First results show that infrastructural elements, group size and individual variations (handicaps, preliminary experience with similar situations or infrastructure) all influenced the speed of egress, speeding it up or slowing it down. Especially, an influence of (social) human factors was found. Examples are supporting the movement of handicapped or slower persons, staying with one's group or relying on guidance of others familiar with the infrastructural specificities. Also, spontaneous "knots", as a result of individual factors or social adhesion of groups, were found.

These results are relevant for underground evacuation because evacuation of passengers is not only slowed down by architectural bottlenecks but also by infrastructural factors, individual and social factors. In further field experiments phenomena will be investigated with larger numbers of passengers, for possible cultural variation and different types of infrastructures.

REFERENCES

Berlonghi, A. (1993). *Understanding and planning for different spectator crowds*. In Smith, R. and Dickie, J. (Eds.). (1993). *Engineering for crowd safety* (S.13-20). Amsterdam: Elsevier.

Clarke, L. (2002). *Panic: Myth or reality?* *Contexts*, 1 (3), 21-26.

Dynes, R.R. (2006). *Panic and the vision of collective incompetence*. *Natural hazard observer*, Vol. XXXI (2).

Fahy, R. F. & Proulx, G. (2009). *'Panic' and human behaviour in fire*. Paper presented at the 4th International Symposium on Human Behaviour in Fire, Robinson College, Cambridge.

Forell, B. (2004). *Bewertung der Anforderungen der Musterversammlungsstättenverordnung (Mai 2002) hinsichtlich realistischer Evakuierungsszenarien in Diskotheken und ähnlichen Vergnügungsstätten*. Braunschweig: TU Braunschweig.

Helbing, D., Farkas, I., and Vicsek, T., *Freezing by heating in a driven mesoscopic system*, *Physical Review Letters* 84, 1240-1243 (2000).

M. Moussaïd, M., Helbing, D. and Theraulaz, G. (2011) *How simple rules determine pedestrian behavior and crowd disasters*. *PNAS* 108 (17) 6884-6888.

Schadschneider, A., Klingsch, W., Klüpfel, H., Kretz, T., Rogsch, C. and Seyfried, A. (2009). *Evacuation dynamics: Empirical results, modeling and applications*. In B. Meyers (Hrsg.), *Encyclopedia of Complexity and System Science* (S. 517-550). Berlin: Springer.

Schreckenberg, M. (2010). *Dynamik von Menschenmassen*, AKNZ Seminar, 22.06.2010. Deutsche Hochschule der Polizei, Brühl.

Sime, J. D. (1995). *Crowd psychology and engineering*. *Safety Science*, 21(1), 1-14.

Thiel-Clemen, T., Klingenberg, A. (2010). *Kombination von zielorientiertem Verhalten und Emotionen in Individuen-orientierten Simulationen*, in: Wittmann, J. and Maretis, D. (Hrsg.), *Simulation in den Umwelt- und Geowissenschaften*. Osnabrück: Shaker. 71-80.

Tubbs, J. S. and Meacham, B. J. (2007). *Egress design solutions: A guide to evacuation and crowd management planning*. Hoboken, NJ: John Wiley and Sons.

Getting out of the way: collision avoiding pedestrian models compared to the real world

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Numerical simulation of human crowds is a challenging task, and a number of approaches to simulate pedestrian dynamics on a microscopic level have been established. The aim is to model a realistic, and in particular collision-free, movement of crowds in complex environments.

One possible approach to achieve this goal are Cellular Automata (CA). CA models represent the environment with a grid-like structure, where each cell of the grid may contain at most one pedestrian at a time. CA models have often been used for the simulation of evacuation scenarios. A common problem with existing CA models, however, is that they do not model complex wayfinding, since in most CA models wayfinding is implemented via a globally defined potential field. In theory, it would be possible to assign an individual potential field to each pedestrian. This approach, however, would be too complex in terms of computational costs for large scenarios.

Other simulation concepts use (discretized) differential equations similar to equations known from the description of Molecular Dynamics (MD). Probably the best known model based on the MD analogy is the social force model. In social force model simulations, each pedestrian has a desired velocity towards a desired destination and adapts her current velocity accordingly. A pedestrian's incentive to avoid obstacles such as other pedestrians is modeled by repelling forces. Force-based models are well understood and have reasonable computational costs.

There is a third class of models that try to achieve collision free pedestrian movement in complex environments. These models are based on the so called configuration space obstacle approach and have their foundation in robotics. In this context the configuration space describes all possible locations a pedestrian can reach. Locations that cannot be reached are the so called configuration space obstacles. For this approach the pedestrians and the obstacles in the environment (e.g. walls and other pedestrians) have to be represented as a set of simple polygons. A path through the environment is collision free if the path does not intersect the Minkowski sum of the polygonal obstacles with the polygonal representation of the pedestrian reflected in her reference point.

An extension to the configuration space obstacle approach is the velocity obstacle approach. Similar to the configuration space obstacles the velocity obstacles describe all velocities a pedestrian can choose that will lead to a collision at some point in time assuming straight movement and no acceleration of rest of the pedestrians. In the velocity obstacle approach every pedestrian chooses at each point in time a velocity that avoids collision and is close to the desired velocity. This work investigates two approaches for explicit collision avoidance for multi-destination pedestrian crowds simulations in complex dynamic environments.

The first approach is an extension to an existing collision avoiding force-based model (Zanlungo et al., 2011). In the force-based model the repelling forces do not only depend on the locations of the obstacles and pedestrians but also on their velocities. When calculating the actual force that affects a given pedestrian the model first calculates the minimal time of closest approach to all other pedestrians and obstacles in the environment. All pedestrians are then projected up to this point in time assuming constant movement. The influencing force on the pedestrian in question is calculated based on this projection and weighted by the inverse of the minimal time of closest approaches times. This leads to a behavior that always tries to avoid the next potential collision under the assumption of constant movement. Like in other force-based models, too, each pedestrian has a desired velocity to which she adapts in a given time if free movement is possible. In our approach, complex wayfinding is implemented via a navigation graph and a shortest path search: a force that lets a pedestrian move along the navigation graph replaces the simple desired velocity vector. With this model it is possible to simulate pedestrian movements to multiple destinations in a complex environment.

The second approach discussed in this paper is based on the velocity obstacle approach (see v. d. Berg et al., 2008). But instead of calculating valid velocities during every time step the pedestrians choose valid accelerations preferably close to the desired one. Therefore, we refer to it here as acceleration obstacle model. This approach leads to the same result as choosing a valid velocity directly but lets the model be better integrated with force-based models. This integration is needed since the calculation of the desired velocity and the short-range interaction is still based on forces. Like with our first approach, desired movement is based on a force that lets each agent move along a navigation graph.

Both models are tested on data from a real-world experiment conducted by us (see, Plaue et al., 2011). The participants of the experiment have been divided into two groups, and each of the groups was instructed to walk along a given path. These paths were arranged such that the two pedestrian groups intersect at an angle of about 90 degrees. The experiment has been recorded and the individual trajectories have been extracted afterwards from video. In this paper the performance of the force-based model and the acceleration obstacle model are evaluated by comparison with the real-world data in terms of the spatial-temporal distribution of pedestrian densities. To this end, we calculate a local density field via kernel density estimation similar to (Helbing et al., 2007) but with variable kernel bandwidth. A further investigation discussed in this paper is the performance of both approaches in terms of computational costs. At the end of the paper a final appraisal is given which of the models is most appropriate under which conditions.

REFERENCES

- J. van den Berg, M. Lin and D. Manocha: „Reciprocal Velocity Obstacles for Real-Time Multi-Agent Navigation“, *IEEE International Conference on Robotics and Automation (ICRA 08)*: IEEE, pp. 1928-1935
- D. Helbing, A. Johansson, and H. Z. Al-Abideen: „Dynamics of crowd disasters: An empirical study“, *Phys. Rev. E* 75, pp. 046109 (2007)
- M. Plaue, M. Chen, G. Bärwolff, and H. Schwandt: „Trajectory extraction and density analysis of intersecting pedestrian flows from video recordings“, *Proc. PIA11, LNCS 6952*, 285-296 (2011)
- F. Zanlungo, T. Ikeda, and T. Kanda: „Social force model with explicit collision prediction“, *EPL (Europhysics Letters)*, 2011, 93, 68005

Methodology for pedestrian simulation with complex/random routes in public spaces

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Usually, during the functional design or evaluation of a public space, it is essential to have a tool that guarantees the suitable operation of the designed spaces. Modern railway stations, for instance, are increasingly becoming sophisticated spaces that combine the commercial plurality of a shopping center with the complex boarding processes of an airport.

In this kind of spaces -airports, stations, intermodal transportation hubs etc.- people find a high variety of waypoints or intermediate activities in their journey (such as restaurants, shops, baths, cash dispensers, stands or screens, among others). Those waypoints usually reach the hundred, or even more. In such cases, the number of possible routes for pedestrians along their journey towards their final destination grows exponentially. This leads to a huge combination of feasible pathways. Modelling pedestrian methodologies so far used, are usually based on a O/D-based fixed percentage of routes, that allocates people in them in order to move around the modeled space, through one or several intermediate activities before they reach their final destination. These conventional and simple methods are, therefore, no longer enough to represent the complexity of such spaces. They are just unable to reproduce the complexity of real-time decision making for pedestrians.

Thus, it is important to develop and implement a methodology able to reproduce and assess those complex pedestrian movements inside this kind of spaces. This methodology has to be simple enough as not to be too cumbersome or calculation-intensive for a common PC, if we want it to be practical. Being said this, it is necessary to leave behind conventional solutions based on simplistic approaches to the real situation, and to find a method precise enough to become a practical tool in the decision-making process.

On the basis of these principles, it has been developed a methodology which reproduces the behavior of people in public spaces. From a deep knowledge of current situation, people behavior has been analyzed and processed in each case, effectively identifying behavior-patterns that are used as the basis for validation of these pedestrian models, and for the design of future scenarios as well. This method has already been successfully applied in the two major railway stations in Madrid, Chamartín Station and Atocha Station for the Spanish Railway Infrastructure Administrator (Adif).

The key component of this methodology involves important field surveys campaign: O/D matrix, counts and commuter tracking, used to identify all the steps/waypoints of users inside these venues. Those surveys have achieved more than 5,000 commuters trackings in Chamartín Station and more than 11,000 trackings to commuters in Atocha Station. Those trackings follow people from the moment they enter the studied space to the moment they left, covering all operating hours and intermediate

stops. Final reports were expanded to the total daily demand so every user in the station had a register line with exhaustive information data about their waypoint “chain”. The trackings included other necessary information to precisely characterize every user such as:

- Time the user enter the scenario.
- No. of entrance.
- Movement 1.
- Time the user is arriving movement No. 1.
- Time the user is leaving movement No. 1.
- Movement “i”.
- Time the user is arriving movement No. “i”.
- Time the user is leaving movement No. “i”.
- Final destination.
- Train schedule.
- Truck number.
- Time the user reaches the final destination.
- No. of exit.
- Luggage (shoulder bag, bag, small suitcase, large suitcase etc.)
- Age range.
- Sex of the user.
- Type of user (boarding travelers, passing users, transit users etc.)

Passenger daily demand of Chamartín Station in 2010 was over 39,000 people, and Atocha Station exceeded 215,000 boarding passengers a day. Having in mind those figures, it is clear that a specific methodology is required in order to effectively solve the problem of analyzing their behavior, and its subsequent application in a pedestrian model.

In the case of Chamartín and Atocha Stations, pedestrian models were built using Legion software. The flexibility of this software package allowed the implementation of the routing methodology, redirecting people inside the station through their probabilistic routes without knowing them in advance.

Since the routes depend on the type of passenger, time of the day, and type of waypoints (restoration areas, ticket machines, waiting areas, etc.), it provided not only a great tool to calibrate/validate a realistic model, but to assess the behavior of the model in future scenarios varying the space allocation for the commercial and operational areas.

As a whole, the development of a specific methodology allowed to solve the problem of the analysis of important data in the tracking campaign database from the field survey and its direct application in the development, calibration and validation of the pedestrian model, a key element in the decision-making process.

Collection of data stemming from the fine trajectory of the pedestrians

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One of the main of a scientific approach is to understand what is real. For this, we must identify the phenomena which could that explain in different ways. One way to study these phenomena is to build a model, in order to simplify the representation of the observed phenomena to be relevant. To build a relevant model, we choose some representative data and we made a number of assumptions about the behavior of the phenomena studied. As part of a study on the behavior of pedestrians, most theoretical models (e.g. to help understand an organization or socio-spatial dynamics) are far from realistic. Business models (e.g. for town and country planning decision making) or predictive models (e.g. to try to predict future development of cities) lack of data experimental to be validated experimentally. This work is a part of a project to experimentally validate some pedestrian model with experimental data. In order to know the strategy adopted by pedestrians when they get around. We need to analyze and to understand the physical interactions (movement and force between individuals) among a crowd. The mechanisms that underlie the dynamics of human crowds are little known. They are rather studied in psychology and sociology, to analyze the relationship between pedestrians (Silcock D., R. Walker, 1998). This analysis is mainly the subject of a qualitative study.

Another focus for pedestrians is to consider measurements in real conditions. For instance, in a hall, it could be interesting to measure the path taken by pedestrians, but also the speed or the acceleration. In fact it would allow a detailed analysis of the approach of the stride. A consequently an analysis rather quantitative. Our work place in this context and narrowly combine observations in natural environment with controlled experimentations. Currently we develop a high precision whose purpose is to track the moving in an indoor area. The latter would be widely sufficient to represent interesting space for researchers in pedestrian mobility. The association of speed and position sensors, like input devices of this real-time system, should improve tracking applications. As a result several applications could be carried out: crowd tracking, tracking of consumers in shopping malls, tracking in evacuation cases, to predict the quality of pedestrian traffic in different conditions, to evaluate the right architecture for capacity of buildings.

Our project relies on literature based on observations and descriptions of pedestrian behavior (K. Teknomo, 2002) (SP Hoogendoorn, 2004). Two pedestrian approaches set up the tracking system.

- Kinematic: Results of studies in this area are not homogeneous (TF Novacheck, 1998) (T. Fugger, Jr., B. Randles, 2000) (A. Toor, A. Happer, 2001), but these numeric values give a good indication of the orders of magnitude. Hence they never must be considered like absolute references.
- Mechanical: The pedestrian is a complex structure of 41 degrees of freedom (A. Ebel, D. Hanon, 2002.). He can be modeled by a mechanical system with six degrees of freedom (3 in rotation and 3 in translation).

Both kinematics (changes according to the density of the crowd) and mechanical structure (must be taken into account like a rigid object to reduce the calculating power of our system) of the pedestrian will have to be considered to answer to system specifications of our project.

To combine these two approaches, we selected some representative data and we made a number of assumptions on the densities of crowds. From these assumptions, we determined a density of 1.1 person per square meter error of about 5 cm on the position. The system must have a refresh rate of 4 Hz for a good trajectory.

In terms of interaction with the environment, coordination and organization of collective movements result from interactions between individuals but also the interactions that individuals establish with their environment. The environment will influence the movement of individuals acting either on the individual himself, or on the signal (tactile, acoustic, visual). It is important to note that individuals will also act on their environment in return. We focused initially on the role of the environment on these mechanisms by developing a highly collaborative and non-intrusive. Pedestrians are not aware followed, or as little as possible to be, so if they move in the usual way.

The fact of being based on knowledge of physics, means that we will not make any assumption about the mode of human intelligence to be the source of orders that will cause the movement of pedestrians. We simply choose a system based on the data available on the system input only. The use of pressure carpet or infrared stereo vision seem better suited to the problem.

In the detection step, the ability of the carpet to feel the pressure per pixel allows the floor to locate and analyze the speed and direction changes in the pedestrian environment. Identification and tracking of users by stereo camera allow analysis of interactions with high precision. One of the two systems will be retained and presented after a laboratory test. In addition, some social factors that may cause embarrassment or that can inspire social interaction around the pedestrian will be explored.

This paper therefore presents a tracking system capable of storing detailed kinematics of pedestrian behavior in an environment. Its mechanisms are consistent with studies in the physical sciences on the behavior of pedestrians. Our system fosters an individualized study, each pedestrian is treated as an individual and treated as a separate entity. It is, moreover, able to memorize the kinematics of several hundred people in real time.

REFERENCES

[1] A. Ebel, D. Hanon, B. Stanciulescu, P. Pudlo, E. Grislin, F-X. Lepoutre (2002). *Modèle d'animation comportemental de piétons virtuels*

[2] A. Toor, A. Happer, R. Overgaard, and R. Johal, "Real world walking speeds of young pedestrians," in SAE, 2001.

[3] D. Silcock, R. Walker, and T. Selby, "Pedestrians at risk," in PTRC proceedings of European transport conference, 1998, pp. 209-219.

[4] K. Teknomo, "Microscopic pedestrian flow characteristics : Development of an image processing data collection and simulation model," Ph.D. dissertation, Departement of Human Social Information Sciences, Graduate School of Information Sciences, Tokohu University, Japan, Mar. 2002.

[5] S. P. Hoogendoorn, "Pedestrian modelling by optimal control and differential games," in *German - Dutch - Finnish Seminar on Traffic Engineering*, Feb. 2004.

[6] T. F. Novacheck, "The biomechanics of running," *Gait & Posture*, vol. 7, pp. 77–95, 1998.

[7] T. Fugger, Jr., B. Randles, A. Stein, W. Whiting, and B. Gallagher, "Analysis of pedestrian gait and perception-reaction at signal-controlled crosswalk intersections," *Transportation Research Record 1705*, pp. 20–25, 2000. [Online]. Available : <http://www.enhancements.org/trb%5C1705-004.pdf>

Keynote

Thursday, 7 June - 16.10

Chris Kemp, Buckinghamshire New University, Uxbridge UNITED KINGDOM

New developments in crowd management, safety and dynamics:

Managing risk for safer crowded places

In my talk I will present a series of aspects focusing on crowd management, safety and dynamics that focus on the managing risk for crowded places. In recent years the development of modelling for crowded spaces has become more realistic in its development and through a range of activities such modelling can become even more honed so that the delivery of real time and realistic movements across a range of environments can be enhanced. The first part of the presentation will focus on the underpinning traits of play associated with the crowded space. The second part looks at the uses of profiling tools. The third part reviews the management of the space itself.

The final parts of the presentation focus on voronoi modelling and the creating of activities linked to crowded spaces and finishes by looking at the ever present threats which need to be modeled to understand the total environment encompassed within a crowded space.

Special session

Thursday, 7 June - 16.40

Dinesh Manocha, University of North Carolina, Chapel Hill NC USA

Computer vision, graphics and robotics

From record-setting crowds at rallies and protests to futuristic swarms of robots, our world is currently experiencing a continuing rise of complex, distributed collections of independently acting entities. With potential applications such as computer graphics, predicting crowd disasters, improving robot cooperation, and enabling the next generation of air travel, developing models to reproduce, control, predict and understand these types of systems is becoming critically important.

In this talk, I will give an overview of how to use velocity-space planning techniques to compute cooperative motion paths for a group of independent entities sharing the same physical space. I will focus on the special case of simulating human-like crowds, with applications to computer animation and architectural analysis. Specific topics will include optimization-based strategies for distributed collision avoidance, uses of the principle of least effort for simulating crowds, and data-driven strategies for modeling differences in personalities. The talk will also cover related techniques needed to achieve accurate simulations of large-scale crowds such as efficient parallel/SIMD compute models and methods of validating simulations against real world data and will discuss how velocity-space motion planning can be applied to collision avoidance for distributed robotic systems.

Mubarak Shah, University of Central Florida, Orlando FL USA

Computer vision, graphics and robotics

In this talk I will present our recent computer vision method for human detection and tracking in a video sequence. Our approach learns part-based person-specific SVM classifiers which capture the articulations of the human bodies in dynamically changing appearance and background.

With the part-based model, our approach is able to handle partial occlusions in both the detection and the tracking stages. In the detection stage, we select the subset of parts which maximizes the probability of detection, which significantly improves the detection performance in crowded scenes. In the tracking stage, we dynamically handle occlusions by distributing the score of the learned person classifier among its corresponding parts, which allows us to detect and predict partial occlusions, and prevent the performance of the classifiers from being degraded.

Keynote

Friday, 8 June - 09.00

Andrew Hutton, Network Rail, London UNITED KINGDOM

London Bridge – the significant role ped modelling plays in designing the new station and how to deliver it

This presentation will take delegates through the various steps we used pedestrian modelling for in determining an acceptable design for the new London Bridge station. It will highlight how we considered the existing demand, understood the operational constraints and factored those against the design aspirations and requirements, which included a growth profile of over 60%. This was then subjected to both static and dynamic modelling to validate the designs.

This work has been very well received by both the client and stakeholders, who gained great confidence in the process. Therefore, a very similar approach is also being used to consider any proposed alterations to the design as well as all impacts that the eight large construction phases will bring to the station. All the work has to be carried out whilst maintaining the railway operations of the fourth largest station in the UK, which handles 1000 people per minute in the peak hour!

Oral presentations

Friday, 8 June - 09.30

- A.19 *Hubert Klüpfel, TraffGo HT GmbH, Flensburg GERMANY*
PedGo Guardian: an assistant for evacuation decision making
- A.20 *Qiuping Li, Wuhan University, Wuhan CHINA*
Ant colony based evacuation optimization algorithm for mixed vehicle-pedestrian flows
- A.21 *Kerry L. Marsh, University of Connecticut, Storrs CT USA*
Crowd guidance in building emergencies: Using virtual reality experiments to confirm macroscopic mathematical modeling of psychological variables
- B.19 *Anders Johansson, University College London, London UNITED KINGDOM*
Utilizing crowd insights to refine disease-spreading models
- B.20 *Sean Curtis, University of North Carolina, Chapel Hill NC USA*
Pedestrian simulation using geometric reasoning in velocity space
- B.21 *Daichi Yanagisawa, College of Science, Ibaraki University, Ibaraki JAPAN*
Influence of rhythm and velocity variance on pedestrian flow
- C.19 *Tao Chen, Tsinghua University, Beijing CHINA*
Study of human behaviour before evacuation
- C.20 *Elise Miller-Hooks, University of Maryland, College Park MD USA*
Modeling pedestrian route choice during large public gatherings
- C.21 *Alexander Mordvintsev, National Research University of Information Technologies, Mechanics and Optics, St. Petersburg RUSSIA*
Simulation of city evacuation coupled to flood dynamics

PedGo Guardian: an assistant for evacuation decision making

Tim Meyer-König, TraffGo HT GmbH, Flensburg GERMANY
Hubert Klüpfel, TraffGo HT GmbH, Flensburg GERMANY

In modern societies, urbanization and large scale entertainment are obvious trends and consequently, large and complex multi-functional arenas are part of most large cities. The guidance of pedestrian flows in such buildings is a challenge. The Hermes research project, funded by the German Federal Ministry of Education and Research within the Security Research Program, aims to protect and save lives by developing an “evacuation assistant” that could allow stadiums and their venues hosting large events to be cleared quickly and more safely than currently possible. The Hermes system is designed to use information about a current situation to predict what will be the future positions of the occupants. It involves feeding data into a computer program about the availability of rescue routes, fire protection systems, and the distribution of people as determined using video cameras linked to image-processing software. This allows for flexible reactions to the actual situation for which usually no special emergency plans exist.

In this contribution, we will focus on the “Guardian” mode which has been ported to the PedGo evacuation simulation software.

DESIGN OF EVACUATION SYSTEMS

The dimensions of escape routes are specified in building design codes. Since the reference case is the ESPRit arena in Düsseldorf, Germany, we make reference to the German regulations (“Versammlungsstättenverordnung”, resp. SBauVO, part 1). For a non-roofed sports stadium, a width of 1.20 m per 600 persons (minimum: 1.20 m, increasing in steps of 0.60 m) is required. For roofed sports stadiums the requirements are: 1.20 m per 200 persons, and an additional 0.60 m for every 100 additional persons). In addition to that, different maximum distances are specified such as to a “safe area” (which might be a fire protected staircase).

The general design process for pedestrian traffic also applies to route elements of an evacuation system. As mentioned above, the design criteria according to the prescriptive codes are the length and width of escape route elements. Therefore, prescriptive codes are static approaches not taking into account the crowd dynamics aspects of an emergency evacuation. The Hermes evacuation assistant and consequently also PedGo Guardian on the other hand, are not only design tools but also cover the operation of the stadium, e.g. the crowd management. To this end, video analysis techniques like detection and tracing are used to adjust the simulation and provide information about the current positions of all persons in the arena.

Based on the forecast of the simulation, the security staff can prepare for events to come and can test different strategies to handle a potentially hazardous or very uncomfortable situation. In order to assess

the different strategies and their consequences, a level of hazard concept based on the level of service and the crowd density and movement characteristics is used.

The levels A to F are grouped into three broader categories. “Green”, “yellow”, and “red” are the levels used in the evacuation context. For the Hermes project, this more basic scheme is adopted to make it applicable for a command and control center.

EVACUATION SIMULATION

Evacuation simulation is a core part of an evacuation assistant. Fast microscopic simulations like PedGo can predict the motion of more than 50,000 persons easily in real time on standard Desktop or Laptop computers. They do take into account individual properties and personal differences concerning physiological (like walking speed) and psychological characteristics (like orientation). The information of the detection system about the position of all persons in the arena is processed by the simulation kernel. Similar to a weather forecast, the kernel then computes a prognosis for the situation in the future. For the case of an evacuation, this forecast covers the complete process, i.e. it runs until the last person has reached a safe place of refuge.

An example for the initial situation for a football match with all persons placed initially on the stands is shown in figure (will be part of the full paper). The red dots indicate persons sitting on their seats. The cumulative local density is one major criterion for identifying congestion. In figure x the areas where this cumulative local density exceeds 3.5 persons per square meter for more than 10% of the overall egress time is marked red.

EVACUATION ASSISTANT

The evacuation assistant will be used by the staff in the command and control center to assess the situation and plan the operation of the security staff and forces.

The density criterion shown in the table above is only one for assessing critical situations. The green/yellow/red scheme will assist the security personnel to focus their attention. As long as a situation is “green”, no specific attention is necessary. Yellow requires special attention and preparation for crowd management measures and other interventions. Finally, red situations are not acceptable and require specific and immediate action like crowd control. Of course, the challenge is the definition of the demarcation criteria between the different regimes and the calibration of the intervention and action catalogue.

Ant colony based evacuation optimization algorithm for mixed vehicle-pedestrian flows

Qiuping Li, Wuhan University, Wuhan CHINA
Zhixiang Fang, Wuhan University, Wuhan CHINA
Qingquan Li, Wuhan University, Wuhan CHINA

RESEARCH MOTIVATION

Although multi-agent simulation tools are increasingly used for transportation simulation in recent years, effective mechanisms to simulate the mixed vehicle-pedestrian flows under congested evacuation situations still remains at its infancy. Different from vehicles, pedestrian does not follow strict traffic rules and they spontaneously stop, change directions or make sudden turns . Due to real world situations, especially in the developing countries (i.e. China and Indian), we should research the mixed vehicle-pedestrian flows in evacuation. The traditional transportation simulation models usually focus on vehicles in the road networks or the pedestrians in the building environment. Viswalk, a newly developed simulation module, can be integrated with Vissim to simulate the interactions between pedestrians and vehicles (Viswalk, 2011). However, approaches to integrate the simulation model with the optimization model for planning the optimal multi-modal evacuation process are still very few. In this paper, we propose a two-tier architecture to simulate the mixed vehicle-pedestrian flow and optimize the evacuation process. One tier is designed to find path of vehicles and pedestrians optimized by ant colony algorithm (ACA), and the other tier is for simulating the movements of vehicles and pedestrians dynamically.

METHOD

The first tier is for the optimization purpose. It calculates the paths which pedestrians or vehicles will move along step by step. Each pedestrian or vehicle is viewed as an ant in ACA. The total length of space-time paths for all pedestrians and vehicles is considered as the optimal objective. This objective can involve both the influence of evacuation time and evacuation path length. We use a probability selection and a positive feedback strategy to find the optimal paths in emergency situation. In each step, all the possible paths for each vehicle and pedestrian are found and assigned to them according to a roulette wheel selection method. The traffic flow calculated in the last step will guide the next-step pathfinding of ant or ant group in the micro-simulation process. After a certain times of iteration, if the objective value remains relatively stable, the paths found by the ants for pedestrians and vehicles can be viewed as the system optimal paths in the multi-modal evacuation situations.

The second tier simulates the dynamic moving process of vehicles and pedestrians. Mixed flows in links and intersections of an evacuation network are modeled and simulated separately. In the links, this study simulates the pedestrian flow and vehicle flow with the separated queue model. For example, vehicles moves on vehicle lanes and pedestrians walks on footpaths. Lateral friction is ignored between these two traffic modes. At the intersections, the space is divided by cells. A pedestrian occupies one cell and a vehicle takes several cells, but each cell can only be used by a vehicle or a pedestrian. The basic rule for an ant to choose a cell is based on the least travel time to this cell. The conflict of different

pedestrians or vehicles competing for one cell is solved by FCFS (first come, first serve) principle. Based on the simulation results (e.g. link density and conflict degree of pedestrians and vehicles, etc.), each vehicle or pedestrian can find a reasonable path in the evacuation network according to the time-dependent traffic flow.

EXPERIMENT RESULT

An experiment on a stadium evacuation is implemented. The people in the stadium is divided into two classes, one class need to escape the stadium by walking, and the other class want to pick up their cars and drive to escape from the stadium area. The area within 1km radius from the the stadium is considered as the evacuation network. The evacuation network in this study includes 272 nodes and 644 links with directions. The proposed two-tier architecture has been implemented in C++ language and runs on a PC with 3.06 GHZ, 3GB RAM. The ACA runs for 100 generations, and the average space-time length goes down gradually from 4020 in the 1st iteration to about 3000 in 40th iteration, and then the evolution process keeps relatively stable.

CONCLUSION

In this paper, we proposed a two-tier architecture to integrate the simulation model with the optimization model for planning the optimal multi-modal evacuation process. Because of the significant difference in moving rules, traditional transportation simulation models have some difficulties in modeling the dynamics of both pedestrians and vehicles, especially in modeling the interactions of these two travel modes. Moreover, the network MOEs (measure of effectiveness) could be overestimated if we ignore the interactions between different travel modes. Our experiment results show that our approach is useful in the evacuation plan optimization for pedestrian-vehicle mixed flows in evacuation networks. However, it must be noted that the proposed micro-simulation model for dynamics of pedestrians and vehicles needs to be further improved since the results obtained by the proposed model cannot be validated due to a lack of experimental information on human performance under emergency condition.

REFERENCE

Viswalk(2011): <http://www.vissim.de/software/transportation-planning-traffic-engineering/software-system-solutions/viswalk/> (accessed on 2011-11-10)

Crowd guidance in building emergencies: Using virtual reality experiments to confirm macroscopic mathematical modeling of psychological variables

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Crowd evacuation behaviors including disorder and blocking have been observed in recent tragedies such as the 2003 Rhode Island and 2009 Bangkok nightclub fires [1][2]. Behavioral studies of evacuees have shown that psychological stress plays an important part in the emergence of disorder and blocking [3][4]. However, there is a discrepancy between theories that explain the behavior of evacuees and the methods of providing effective guidance to evacuees in building emergencies. With recent advances in fire detection methods and crowd communication, there is potential to alleviate these kinds of injuries and deaths in the future. Thus it is important to redress this gap between theory and our ability to guide crowds to safety. A critical issue is the elucidating important psychological factors that influence egress for providing effective guidance.

To address the problem of providing effective guidance to crowds, an optimization problem was formulated in our previous work [5]. The underlying equations were chosen to follow a macroscopic model, where crowds are treated as a fluid [6][7] to allow fast optimization. Our model improves upon these models by integrating psychological phenomena that previously have been examined only within computation-intensive microscopic models. In particular, one novel parameter, the desired flow rate (evacuees' feeling of urgency to move), was developed as a macroscopic counterpoint to Helbing's desired velocity [8]. This can help explain the emergence of disorder and blocking during an emergency event. The eventual goal is to solve this problem in real-time thereby providing effective guidance to evacuees during an actual emergency event. Although the current state of crowd guidance falls far short of such an objective, validation of our model is a major step towards realizing this goal.

In this paper we analyze the effects of the psychological factors that are in our model, as well as explore the potential value of including other factors. To partially validate our existing model, an experiment was conducted to confirm what the model implies about the psychological experience of evacuees in such situation. To do this, a virtual reality testing platform was created. This allowed us to run many trials with participants and to better recreate the psychological effects of an emergency event by making the evacuation an embodied, immersive experience. For the virtual reality environment, a university library was chosen due to the potential benefits of guidance at this location. In particular, this library is often crowded with college students who are unfamiliar with emergency exits. A 3D model of one floor was constructed and used in the evacuation simulator Fire Dynamics Simulator with Evacuation (FDS+Evac) [9] to find the evacuation routes and speeds of agents. Graphical avatars were created with their routes and speeds imported from FDS+Evac and displayed during the experiment. The participant thus experienced the evacuation from a first-person perspective.

To better recreate the perception of being in a real emergency, participants wore a head-mounted display and were moved along the same route and speed as a random simulated agent (based on the FDS+Evac output). Several FDS+Evac evacuation simulations were run with varied unimpeded walking speeds. Having a wide range of possible speeds allows us to determine the desired speed for a participant moved at several different speeds on different trials. The three unimpeded walking speeds were uniformly distributed in meters/second as slow $U(0.325, 0.925)$, medium $U(0.95, 1.55)$, and fast $U(1.3, 3.7)$, noting that the unimpeded walking speed for adults is $U(0.95, 1.55)$ in FDS+Evac [9]. In this virtual environment hazardous conditions were also varied by displaying different combinations of smoke and fire. Additionally, during each evacuation trial, fire and emergency alarm sounds were heard through a speaker. Thus, through this manipulation of the environment we attempted to recreate a psychologically realistic emergency event for the participant. Participants gave real-time continuous feedback on their relative desired speed during each trial by moving a joystick forward or backward. Joystick position was expressed as a value between 1 and 7, with values below 4 indicating desire to move slower and values above 4 indicating desire to move faster.

Analyses indicated that hazard condition had a statistically significant effect on joystick position. In the trials involving no visible hazards, i.e., no fire or smoke, the mean position was 4.801. When smoke was visible, the mean position was 5.204. When both smoke and fire were visible, the mean value was 5.717. Thus desired speed increased when hazards were visible, indicating the effectiveness of the virtual environment to induce appropriate psychological responses. Additional findings which indicate the effectiveness of the virtual environment are the changes in desired speed due to the changes in walking speed.

Given the promising results of these findings, we plan to test other psychological factors including excessive urgency to move due to blocking, trust in social versus nonsocial information, and the effects of leadership and social bonds. We are also working on performing fire drills in the same library our virtual environment is created from. Further results will be presented at the Conference and included in the final version of the paper.

REFERENCES

- [1] W. L. Grosshandler, N. P. Bryner, D. Madrzykowski and K. Kuntz, "Report of the technical investigation of the Station Nightclub fire," NIST NCSTAR 2, Vol. 1, 2005.
- [2] S. Mydans, „At least 59 die in Bangkok club fire," *New York Times*, Retrieved on 2009-01-01.
- [3] G. Proulx, "A stress model for people facing a fire," *Journal of Environmental Psychology*, Vol. 13, No. 2, 1993, pp. 137-147.
- [4] R. F. Fahy and G. Proulx, "Human behavior in the World Trade Center evacuation," *Fire Safety Science - Proceedings of the Fifth International Symposium, Melbourne, Australia, 1997*, pp. 713-724.
- [5] P. Wang, P. B. Luh, S. C. Chang, J. Sun, "Modeling and optimization of crowd guidance for building emergency evacuation," *Proceedings of the 2008 IEEE Conference on Automation Science and Engineering, Washington DC, August 2008*, pp. 328-334. DOI: 10.1109/COASE.2008.4626553.

[6] L. G. Chalmet; R. L. Francis; P. B. Saunders, *Network Models for Building Evacuation*, *Management Science*, Vol. 28, No. 1, Jan., 1982, pp. 86-105.

[7] H. W. Hamacher and S. A. Tjandra, *Mathematical Modeling of Evacuation Problems – A State of the Art*, in *Pedestrian and Evacuation Dynamics*, M. Schreckenberg and S. D. Sharma, Ed., Springer, Berlin, 2002, pp. 227–266.

[8] D. Helbing, I. Farkas and T. Vicsek, “Simulating dynamical features of escape panic,” *Nature*, Vol. 407, 2000, pp. 487– 490.

[9] T. Korhonen and S. Hostikka, “*Technical Reference and User’s Guide for Fire Dynamics Simulator with Evacuation, FDS+Evac*,” VTT Technical Research Centre of Finland, April 2009, [http:// www.vtt.fi/ proj/ fdsevac/fdsevac_downloads.jsp](http://www.vtt.fi/proj/fdsevac/fdsevac_downloads.jsp).

Utilizing crowd insights to refine disease-spreading models

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Increasing urbanisation has been accompanied by the rise of ever larger world cities with higher population densities as it becomes more obvious that the economies of scale generated by urban agglomeration lead to increased prosperity. Big cities have become the generators of wealth as they increasingly attract the world's more skilled populations through great streams of migration.

Apart from the strain that such growth is putting on urban living and the provision of urban infrastructure, as the planet gets increasingly crowded, cities in particular are becoming places of more frequent and larger mass gatherings, resulting in massive congestion on road systems and public transport, while local entertainment events generate extreme crowding in small spaces such as sports arenas, festivals and other popular entertainment sites. This extreme crowding is particularly problematic during emergency evacuations.

There are many positive social and economic benefits of bringing people together, but it is widely acknowledged that there are also several negative outcomes. When the density of people (as defined as the number of persons per square-meter) of people grows too high, increased crime, severe traffic delays, and pollution are generated, often more than proportionately through the interaction of populations.

Densely populated areas are also ideal media for certain respiratory epidemics to develop and spread, due to the proximity of people. Frequent interactions between people whose physical contact increases non-linearly with the number located in any particular place, are, as is well known, locations where contagious diseases spread rapidly and reach the largest population in the shortest time.

Even though epidemiological processes are closely related to pedestrian crowding and other modes of transport, the time scales are typically longer and the spatial extents are larger as well. For these reasons, epidemiological models typically operate on a macroscopic system level rather than on a microscopic individual-based level. The advantage of working at a macroscopic level is that the scale of the problem does not become a limiting factor. But there are also disadvantages, for the interventions that one can make to prevent or limit disease from spreading, typically operate on a microscopic individual-based level. Examples of these are immunization, screening, putting people into quarantine, and even setting up some travel restrictions which have to be individually tailored to the travellers in question.

Moreover macroscopic models are typically based on the assumption that populations are in equilibrium, are homogenous, and well-mixed, which we know is not true for real-world populations.

Mobility and interaction patterns in real populations, as reflected in the way that cities are organized, tend to be highly skewed forms of distribution more like power-laws rather than being uniform or normally Gaussian distributed. This typically means that distributions of the population contain clusters on all scales but with few really large clusters and a large number of very small clusters. Diseases will spread faster in the largest clusters but will tend to die out when the cluster size is reached and this has important effects on the actual patterning of the spread of any epidemic.

For all these reasons, we propose a shift in epidemiological modelling from the more top-down macroscopic level [1] to the microscopic bottom-up [2,3]. There have recently been some attempts to move epidemiological models to a microscopic level, for example by running computer simulations of the spread of computer viruses in scale-free networks such as the Internet [4], or in using the international airline transportation network together with census population data to simulate the spread [5]. We propose to go even deeper into the microscopic level and make use of available trajectories of individuals obtained via techniques such as GPS or mobile phone tracking [6], and in this way, begin to track how individuals in small spaces and in closed transport systems such as subway trains enable the spread of disease due to their proximity.

We demonstrate examples of such simulations, showing how an individual-based crowd model can mirror more aggregate Susceptible-Infected-Recovered (SIR) models that have dominated the field so far [1].

REFERENCES

- [1] Kermack WO, McKendrick AG. *A Contribution to the Mathematical Theory of Epidemics. Proc. Roy. Soc. Lond. A. 1927; 115, 700—721*
- [2] Johansson, A., Batty, M., Hayashi, K., Albar, O., Memish, Z., and Marozzi, D. (2011) *Crowd and environmental management during mass gatherings, The Lancet Infectious Diseases, in press*
- [3] Khan, K., McNabb, S., Memish, Z., Eckhardt, R., Hu, W., Kossowsky, D., Sears, J., Arino, J., Johansson, A., Barbeschi, M., McCloskey, B., Henry, B., Cetron, M., and Brownstein, J. S. (2011) *Mass gatherings: Infectious disease surveillance and modeling across geographic frontiers and scientific disciplines, The Lancet Infectious Diseases, in press*
- [4] Pastor-Satorras R, Vespignani A. *Epidemic Spreading in Scale-Free Networks. Phys. Rev. Lett. 2001; 86: 3200–3203*
- [5] Colizza V, Barrat A, Barthélemy M, Vespignani A. *The role of the airline transportation network in the prediction and predictability of global epidemics. PNAS 2006; 103 (7): 2015-2020*
- [6] González MC, Hidalgo CA, Barabási A—L. *Understanding individual human mobility patterns. Nature 2008; 453, 779—782*

Pedestrian simulation using geometric reasoning in velocity space

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Pedestrian dynamics has largely been dominated by cellular automata- and social force-based methods. These approaches each have their own unique properties and costs; to varying degrees they reproduce observable pedestrian phenomena but bear costs inherent in their particular formulation. We present a novel, robust microscopic model for simulating pedestrians and their interactions which captures the same aggregate phenomena exhibited by previous approaches. Furthermore, this new model encompasses a larger space of pedestrian behavior and can be implemented in a numerically efficient and stable manner.

Cellular automata (CA) simulates pedestrians by discretizing the workspace into cells. A cell is occupied by at most one pedestrian. Pedestrians move from cell to cell based on a set of probabilities applied to neighboring cells and then updating agents sequentially and applying collision-resolution rules when multiple agents seek to move into the same cell. CA has been shown to exhibit many emergent phenomena (e.g. lane formation, jamming, etc.)

The social force (SF) model simulates crowds of pedestrians as a particle simulation. Pedestrians have mass and are attracted toward a goal by a driving force. Repulsive forces prevent pedestrians from passing through each other and obstacles. The particle's velocity and position result from the integration of the acceleration imparted by the forces. Like CA, SF gives rise to emergent phenomena (lane formation, jamming, etc.). SF formulations can also exhibit adherence to the fundamental diagram [1]. Unlike CA, SF operates in a continuous space of position and velocity; the simulated pedestrians can be arbitrarily heterogeneous.

We present a novel agent-based model of pedestrian movement: reciprocal velocity obstacles. We assert that humans have the ability to estimate speed and future positions of other pedestrians. Consider two pedestrians, A and B. When A observes B, A estimates the path of B. If A determines a collision is probable, A will adjust its path, otherwise, A will continue along its original path. Reciprocal velocity obstacles (RVO) model this estimation and adaptation.

RVO has its origin in robotics. A velocity obstacle (VO) is a geometric construction in velocity space. Pedestrian B creates a velocity obstacle for A, which corresponds to the set of all velocities that A could take which would lead to a collision with B (assuming constant velocity for B) [4]. Each neighbor of A likewise defines an additional velocity obstacle for A. Given A's preferred velocity (the velocity the agent would take in the absence of others), A's collision-free velocity is the velocity lying outside the union of velocity obstacles which „best“ approximates the desired velocity.

Using velocity obstacles directly, each agent would view other agents as unresponsive dynamic obstacles. However, the other agents are, in fact, responsive. This oversimplification can easily lead to oscillations because each agent overreacts. Furthermore, it is not consistent with observed human behavior in which both adapt their paths to avoid collisions [2]. The RECIPROCAL velocity obstacle captures this natural behavior. In our model, the change in relative velocity required to avoid collision is computed and apportioned between the agents equally so both agents exert effort to avoid collision. Furthermore, this reciprocity can be modeled in such a way as to guarantee mutually compatible, collision-free velocities between the agents [4].

It has been observed that as the density of a group of pedestrians increases, the average speed of that group decreases. This relationship is called the fundamental diagram. This phenomenon has several origins. First, biomechanical research has shown that walking stride length grows with speed. Dense crowds admit less space for stepping which leads to lower speeds. Second, pedestrian estimation of the available space will invariably contain error. Therefore, the pedestrians tend to guess conservatively. Finally, the nature of that conservative guess is dependent on a cultural component. Some cultures implicitly value space more than others. We have encoded these three factors into our model and the resulting simulation adheres to the fundamental diagram over a broad spectrum of physical and cultural variation. Finally, as with the previous approaches, RVO-based pedestrian simulation exhibits a wide range of emergent phenomena such as lane formation, arching, edge effects, etc.

RVO-based pedestrians contrast well with CA and SF. It has been observed that CA generates macro-level behaviors consistent with real crowds of pedestrians, but at the micro level (the level of individual pedestrians) the trajectories are “not realistic” [3]. Trajectories produced by RVO are smooth and physically reasonable. Furthermore, CA’s abstraction homogenizes the pedestrians; all agents move at the same, fixed speed. RVO, like SF, allows for a heterogeneous population.

RVO also compares favorably with SF. The repulsive forces used by SF to prevent collisions lead to a potentially stiff system. As the crowd becomes dense, smaller time steps (on the order of 0.01-0.001 s) are necessary to produce stable simulation results. RVO performs computations for collision-free velocities in velocity space. As such, RVO-based pedestrian simulation is stable for quite large time steps (empirical evidence has shown success with time steps as large as 0.2 s.) Authors of SF-based systems have observed that simulation parameters must be specially tuned for each novel scenario [1]. For RVO, experience has shown that a single set of fixed parameter values spans a large range of scenarios. Finally, while SF can generate reasonable pedestrian behaviors, there are reasonable, observable pedestrian behaviors which SF can not generate. For example, picture two pedestrians, A and B, traveling on perpendicular paths, headed toward an inevitable collision. One realistic strategy B could apply to avoid the collision is to increase its speed in its desired direction to pass in front of A. SF cannot reproduce this because the repulsive force from A acting on B will always have a component that is counter to B’s preferred direction and can only serve to retard B’s speed in that direction. RVO computes a „best“ alternative of the preferred velocity. This alternative could lie in a large space of responses including, but not limited to: speeding up to cross in front, slowing to allow the other pedestrian to pass, turning, etc.

Reciprocal velocity obstacles serve as an appealing microscopic model for agent-based pedestrian simulation. The RVO formulation encodes the human ability to predict and adapt. Groups of pedestrians simulated with RVO exhibit emergent behaviors and conform to the fundamental diagram. In practice, the implementation is efficient and robust. Collision-free velocities can be computed for thousands of agents in a few milliseconds on a single core of a CPU.

REFERENCES

- [1] M. Chraibi, A. Seyfried, and A. Schadschneider. *Generalized centrifugal-force model for pedestrian dynamics*. *Phys. Rev. E*, 82(4):046111, 2010.
- [2] J. Pettré, J. Ondre, A. Oliver, A. Cretual, and S. Donikian. *Experiment-based modeling, simulation and validation of interactions between virtual walkers*. In *Proc. Symposium on Computer Animation (2009)*, ACM.
- [3] S. Sarmady, F. Haron, and A. Talib. *A cellular automata model for circular movements of pedestrians during tawaf*. *Simulation Modelling Practice and Theory*, 2010
- [4] J. van den Berg, S. J. Guy, M. Lin, and D. Manocha. *Reciprocal n-body collision avoidance*. In *Inter. Symp. on Robotics Research*, 2009.

Influence of rhythm and velocity variance on pedestrian flow

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INTRODUCTION AND ABSTRACT

Important goals of pedestrian-dynamics research along with elucidation of collective phenomena are development of solutions to ease congestion and contribution to the safety. Thus, we will develop a method to increase pedestrian flow in the congested situation in this paper.

We obtain a flow-density diagram (FDD), which depicts the relation between density and flow by considering the effect of length of stride and pace of walking. It indicates that when pedestrians walk in a constant pace irrespective to the density, the flow increases in the high-density region even if the pace is slower than that in the normal-walking condition. We have performed the real experiment and verified that the pedestrian flow increases when their walking pace is controlled by slow rhythm.

The experimental result also indicates that the rhythm decrease the variance of the pedestrians' movement. Thus, we extend our model to deal the mean and the variance of the velocity of pedestrians independently. In the case that the mean velocity of each pedestrian is same, flow increases when the variance becomes small in a one-dimensional circuit. By contrast, flow decreases when the variance becomes small in a simple evacuation model.

STRIDE AND PACE FUNCTION

We consider the velocity V of an individual pedestrian in detail by dividing it into two parts as $V = SP$, where S (stride function) and P (pace function) denote length of a stride and pace of walking (total number of right and left steps per unit time), respectively.

The explicit formulation of the stride function is intuitively determined as follows. It is plausible to assume that there is the maximum length of stride for pedestrians in the low-density regime. When the density becomes large, pedestrians are no more able to walk with their maximum stride and it decreases linearly as the headway distance decreases.

The explicit formulation of the pace function is determined as follows. If the density is low and a pedestrian does not interact with each other, it is feasible to assume that pedestrians walk with constant pace. However, contrary to the stride function, it is difficult to obtain the explicit formulation of the pace function in the high-density regime with some intuitive assumptions, thus, we consider a simple linear function and investigate how the change of pace affects on the flow.

PEDESTRIAN FLOW

The pedestrian flow is calculated as $Q = rV = rSP$, where r is density. The second derivative of the flow

indicates that convexity of the flow Q in the high density regime is dominated by the characteristic of the pace function, i.e., whether the pace increases, decreases, or remains constant according to the increase of the density.

IMPROVEMENT OF FLOW BY SLOW RHYTHM

Here we would like to newly propose a solution to improve flow in the congested situation from our model, in which the velocity of pedestrians is represented by the product of stride S and pace P . If pedestrians walk with a constant rhythm, in other words if we can control the walking pace by rhythm using a device such as a metronome, the rhythm exactly corresponds to the pace. Therefore, fast and slow rhythms increase and decrease the flow, respectively.

We assume that the pace of pedestrians decreases in the high density regime, i.e., the FDD is convex downward in the normal-walking case. Then we surprisingly observe that the flow of the slow-rhythmic walking case become larger than the normal walking case. This phenomenon may give a safety solution to ease congestion in the real world since the flow increases without any excessive haste.

EXPERIMENT

We have performed the experiment, where pedestrians walk in the one-dimensional circuit. Two kinds of walking were performed in the experiment. In the first case, we did not give any specific instructions to the participants, so that they walked normally. In the latter case, the participants were instructed to walk with the sound from the electric metronome, whose rhythm is 70 beats per minute (BPM). Note that we did not uniform which foot to move first. The experimental results indicate the followings:

1. We see that the flow is larger in the normal case than the rhythmic case in the low-density regime, so that we have verified that 70 BPM is slower than the normal-walking pace.
2. The flow increases linearly as the density increases in the low-density regime in the both cases, so that we have verified that participants walked with constant stride and pace.
3. The flow decreases linearly in the high-density regime in the rhythmic case as expected from our analysis.
4. We observe that the flow in the normal case is convex downward in the high-density regime as we have assumed in the theoretical analysis.
5. Since the theoretical assumptions of the convexity are satisfied in the experimental flows, the crossing appears, and the flow of the rhythmic case exceeds that of the normal case in the high-density regime. Therefore, we have succeeded to verify that slow rhythm improves the pedestrian flow.

EFFECT OF VARIANCE

The experimental errors are small; however, we observe that they are smaller in the rhythmic-walking case than in the normal-walking case in the high-density regime. This result implies that rhythm removes the heterogeneity of pedestrians' movement, synchronizes it, and contributes to the homogeneous spatial distribution, which achieves improvement of the flow.

In order to verify this phenomenon, we have extended our model to deal the mean and the variance of pedestrians' velocity independently by applying a unit conversion of physical quantities in stochastic cellular-automaton models with discrete time. We can focus on the influence of variance on the flow by removing the influence of mean using this method. Our theoretical results indicate that flow increases when the variance of velocity decreases in the case that pedestrians walk in a one-dimensional circuit. By contrast, when pedestrians evacuate through a narrow exit, decrease of the velocity variance decreases the flow since plural pedestrians try to go through the exit at the same time and conflict there.

Study of human behaviour before evacuation

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Computer simulation is the main method to study evacuation during fire or other disasters. In the evacuation simulation, one of the most important initial parameters is the occupant characteristics, such as the age, gender, education, distribution, accompanied status and pre-movement time. In practice, these parameters are based on assumption and experience. However, due to lack of evacuation and pedestrian data, validation or calibration of evacuation models is still a challenging problem which has not got a good solution. This problem also exists or may be more serious in China. In China, the work of evacuation and pedestrian data collection and study from experiments and real events is less than the European and American countries. Computer simulation studies on evacuation in China often rely on foreign data. Evacuation behaviour during evacuation has strong dependence on human characteristics, such as physical feature, cultural backgrounds, habits and emergency training. Obviously, there must be some differences between Chinese and foreigners for evacuation behaviour. Using foreign data to study evacuation of Chinese crowd will inevitably greatly reduce the accuracy and credibility of computer simulation of evacuation. So, it is necessary to conduct research work on data collection and analysis of evacuation behaviour in China.

In this manuscript, data collection and analysis of evacuation behaviour is carried out by means of questionnaire survey, evacuation drill and case study. We focus on human behaviour before evacuation through questionnaire survey and video information, and pre-movement time is discussed in-depth. Three main parameters are abstracted in this study, namely response time, first action and pre-movement time. The abstraction rules are as follows: Response time means the time that the occupant spends in realizing the emergency and before he/she conducts the first action. First reaction is the reaction that the occupant conducts after he/she realizes the emergency. Pre-movement time, the time that after the emergency occurs and before the occupant chooses the right evacuation route.

We conducted six unannounced evacuation drills in a meeting room. There were about 60 people in the meeting room when we conducted the drill. A certain smoke material was used to simulate smoke from fire, which will produce cold and harmless smoke. Some fire noise is produced from audio equipment in the device room. During the drill, all the people in the meeting room would see the 'fire' smoke and hear the sound of 'fire', but they wouldn't directly face the fire. Three evacuation drills are used to discuss human behaviour before evacuation. The other three evacuation drills are not very successful due to the influence of staff. Also, a questionnaire survey is conducted to make a qualitative analysis of evacuation behaviour. Analyzed and compared with data from three evacuation drills, it comes to results as follows. Firstly, people in different groups respond differently, which results in some difference of pre-movement time. Secondly, according to data from the video information, a bimodal distribution of pre-movement time is gotten. Analysis by gender identity, pre-movement of female is less than that of male,

which could be the reason of bimodal distribution of pre-movement.

Two typical entertainment places fire cases are used to study the human behaviour during fire. Once fire, personnel effective evacuation would be under serious threat and result in fire casualty accidents in typical entertainment places for its complex decoration and high-density of personnel during business. We fortunately got the building structure and video data of these two fire case. Both fire cases result from fireworks, which ignited the ceiling decorated of sound-absorbing foam and other flammable and toxic materials. By the video information, we do the same analysis and study as unannounced evacuation drills. We can observe about 100 people (can't distinguish gender) in one case and 40 people (29 male and 11 female) in another. All the people didn't evacuate immediately until they realized the danger of fire. The bimodal distribution of pre-movement time is also gotten from the two real fire cases, although the mean pre-movement time is less than that of unannounced evacuation drills. The faster beginning of evacuation in real fire case results from the rapid fire development in the entertainment places, which decorated fast burning material.

From the study of unannounced evacuation drills and real fire cases, we got different mean pre-movement time, which are about 18 seconds in real fire cases and about 90 seconds in unannounced evacuation drills. The effect of high temperature field and harmful smoke in real fire will enhance people's consciousness of fire danger. Although pre-movement time is different between unannounced evacuation drills and real fire cases, it shows the same bimodal distribution, which is different from the traditional normal distribution and log-normal distribution. This finding will helpful for computer simulation of evacuation, especially for those who simulate whole process of evacuation.

Modeling pedestrian route choice during large public gatherings

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Effective management of crowd movement is needed in large public gatherings to ensure efficient and safe ingress and egress to and from the event or in the case of evacuation by foot. Such gatherings arise for a variety of purposes and may be held in a myriad of venues, including for example, complex buildings, public transportation stations, sports stadiums and coliseums, amusement parks, commercial shopping facilities, and parklands, among others. In such gatherings, crowds are directed through passageways and open areas designed for the purpose of accessing the event. The physical layout of these passageways provides a set of options from which pedestrians can choose. These options must be designed to support large volumes of people. The speed with which a pedestrian will move through the passageway depends on its physical design and the number of other pedestrians utilizing it at the same time. The time for ingress or egress to or from the event depends on the series of choices the pedestrian makes in navigating the physical layout and the interactions with other pedestrians with similar or competing goals. This paper describes a network optimization-based modeling and solution framework for assessing pedestrian response to the physical layout of a venue's ingress and egress routes during such large public gatherings.

The physical design of a facility is limited by its permanent infrastructure. However, moveable barriers, gates and other devices can be used to organize the space within that infrastructure. How that space is organized affects the speed with which pedestrians within a crowd can move, the shape the crowd can form (e.g. single file), available route options and circuitry. In many cases, it must also facilitate opposing flows for those pedestrians with dissimilar goals.

Given that the pedestrians have information about their route options, how each individual chooses a particular route depends on his or her preferences. That is, each individual assigns his or her own value to different characteristics of the route options. This value system can be captured in a utility function. Within the context of the public gathering, each individual chooses the route to the event or out of the event with the maximum utility.

The concept of route choice in vehicular traffic flow is well developed. Pedestrians, however, have more degrees of freedom in movement and often choose to travel in groups. Such groups arise in vehicular traffic scenarios, but these groups are typically housed within a single vehicle. For example, a family will travel within the same car or larger groups will travel in a bus. These groups, thus, will never be faced with the possibility of being split apart. Others who seek to access the venue together but in different vehicles will often need to be willing to meet at the destination. In the context of pedestrian movement, however, groups must make a concerted effort to move together and not be split apart. For example, parents will not wish to be separated from their children. Thus, while each person within the

family is an individual (i.e. a unit of flow) and is free to make his or her own decisions in response to directives from crowd managers or the physical layout, any effective crowd management plan must facilitate the movement of all members of the family as a group. That is, the group must be permitted to stay together and accommodations must be made to support this group movement. In mathematically modeling the flow of pedestrians through a physical layout, flows, thus, must consist of not only individual movements, but larger movements involving groups of individuals.

The proposed network modeling and solution framework support the movement of both individuals and groups. The approach exploits concepts of utility maximization and recognizes that the utility of a route depends on both fixed route characteristics, such as length or grade, and characteristics that depend on the choices made by others who simultaneously seek passage along the same routes affecting the travel time along the routes for all users. The overall problem of estimating which routes the pedestrians will take given the options, which are bounded by the physical environment, and the features of the options characterized by their utilities, is known as a traffic assignment problem, and is termed a pedestrian assignment problem in this context.

Assignment problems for vehicular traffic have received enormous attention in the literature. Because group behavior is not considered in vehicular transport, the developed models and algorithms for traffic assignment cannot be applied directly in the movement of pedestrians where group behavior must be considered. One reason for this is that the marginal impact of the decision of one flow unit in pedestrian assignment where group behavior is modeled must account for the impact of group size. Moreover, pedestrians are sensitive to different characteristics of the physical environment in comparison to drivers with motorized means of movement. For example, in pedestrian movement, the level of physical exertion required to travel, whether up a flight of stairs, along a ramp or by escalator, should be taken into account. In this paper, a utility function is proposed that incorporates those elements of the route that will impact pedestrian choice.

Using this concept of utility maximization, the pedestrian route choice problem can be modeled as an n-player game, where each player is a group (individuals are modeled as groups of one), each with its own utility function. A pure-strategy Nash equilibrium of the game is sought. This differs from route choice models applied in the context of vehicular traffic, which seek a user equilibrium or similar stochastic user equilibrium, approaches that cannot capture group decisions. This Nash equilibrium approach will be presented in the paper, and results of numerical experiments will be provided to demonstrate its effectiveness in modeling pedestrian response to a venue's physical layout.

Simulation of city evacuation coupled to flood dynamics

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Crowd modelling is one of the key components of risk analysis and evacuation planning in emergency situations. In this paper we present a simulation environment for experimenting with different city evacuation scenarios. In particular we consider the case of city flooding. The simulation couples a flood model with a crowd escape model for scenarios of two city regions: in St. Petersburg, Russia and in Amsterdam, Netherlands.

The model consists of two main parts: hydrodynamic flooding model and crowd escape model. We use a rapid flood-spreading model [1] for floodwater propagation. The model receives water flow rates discharged into floodplain areas from breached or overtopped defences and then spreads the water over the floodplain according to the city topography. The primary outputs of the model are water levels and flow velocities in the area.

The developed agent-based crowd model mimics the behaviour of pedestrians heading from dangerous regions towards safe areas. It uses the output of the flood simulation to drive the evacuation process, to compute available evacuation paths and to track the agents trapped in the flood. Inputs of the model are:

- City topography data, including raster height map (also used for flood modelling), and vector obstacle map, which contains locations of buildings, fences and other obstacles. Some buildings or map areas are marked as Safe Havens.
- Demographics data, including population distribution of agents across the modelled area, the distribution of walking speeds and other agent characteristics.
- Results of hydrodynamic modelling of the flood that consists of water depth dynamics.

The state of every agent is defined by its spatial position, danger awareness, maximal speed, radius (approximating body projection on the ground plane) and the maximal water depth that the agent can traverse. The model also includes some social relationships in our model. For example, some behaviours that cause families to stay together (family members follow the leader who plans the evacuation path and waits for other members in case of walking speed difference).

The crowd model takes the following actions at each time step of the simulation:

1. Acquires the flood simulation result at current time step and updates the obstacle map. Note that the flood and crowd models may use different time steps.

2. Next, a global path map to the safety zones is calculated, this is in the form of a continuous direction field which considers the current water depth and obstacle locations. We use a modified version of Dijkstra's algorithm [2,3] on a Cartesian grid. The agents follow a pre-computed direction at every grid cell, thus reaching the safe zone by a near-optimal route.

3. Agent desired velocity vectors are then updated. Informed agents move along the pre-computed route. Uninformed agents move randomly or stay in one place. Social relationships (following the leader, waiting for family members, etc.) are incorporated at this stage.

4. We use the RVO2 library [4] to implement agent-agent and agent-obstacle collision avoidance logic. The library uses an obstacle map to compute agent velocity vectors avoiding collisions. Here we will also consider the continuous mechanics collision handling methods [3,5,6].

5. In the final steps we move agents according to their velocities and update their knowledge-state. Agents witnessing the water level rise are informed and communicate a warning around them. Agents trapped in areas with too high water are considered drowned.

Results of the proposed model are agent positions, velocities and statuses at each time step. These data are used to analyze junctions, safe shelters, and evacuation effectiveness in different flood scenarios.

Our model uses a global path map for agent path planning. We assume that all agents know the city map and flood direction. Such an ideal situation is possible with an instant information transfer between the agents.

Our current implementation is simulating fifty thousand agents in an area of a few square kilometers several times faster than real-time on a desktop computer. The crowd simulation pipeline is implemented using Python and NumPy. C++ code is developed for computationally intensive parts of the code, such as path planning. We also use an OpenMP parallelized version of RVO2 [4]. With that we have created a simulation environment suitable for experiments with different scenarios of city flooding and crowd evacuation strategies. We have simulated evacuation of Vasilyevsky Island in St. Petersburg and Science Park in Amsterdam. Further we plan to evaluate the efficiency of different control strategies and to experiment with distributed control through individual information devices such as smart-phones.

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REFERENCES

[1] B. Gouldby et al. *A methodology for regional-scale flood risk assessment. Proceedings of the Institution of Civil Engineers*, 2008.

[2] J.N. Tsitsiklis. *Efficient algorithms for globally optimal trajectories. IEEE Transactions on Automatic Control*, Sep. 1995.

[3] A. Treuille, S. Cooper, Z. Popović. *Continuum Crowds*. *ACM Transactions on Graphics, SIGGRAPH*, 2006.

[4] J. van den Berg, D. Ming Lin Manocha. *Reciprocal Velocity Obstacles for real-time multi-agent navigation*. *ICRA*, 2008.

[5] Narain R. et al. *Aggregate Dynamics for Dense Crowd Simulation*. *SIGGRAPH Asia*, 2009.

[6] J. Shopf et al. *GPU Crowd Simulation*. *SIGGRAPH Asia*, 2008.

Poster exhibition

Unsorted list

Abdulaziz Aljohani, University of Birmingham, Birmingham UNITED KINGDOM
Pedestrian crowd dynamics during pilgrimage

Maik Boltes, Forschungszentrum Jülich GmbH, Jülich GERMANY
Tracking people in crowded scenes

Angelika Kneidl, Technische Universität München, München GERMANY
Using a multi-scale model for simulating pedestrian behavior

S.B. Liu, City University of Hong Kong, Hong Kong CHINA
On the simulation for rail tunnel evacuation with cross-passageways

Kristian Schatz, Technische Universität Darmstadt, Darmstadt GERMANY
Investigating human factors in fire evacuation – a serious-gaming approach

Enrico Ronchi, Politecnico di Bari, Bari ITALY
Validation and calibration of the EXIT89 evacuation model for road tunnel evacuation applications

Pedestrian crowd dynamics during pilgrimage

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ABSTRACT

More than three million pilgrims annually gathering in Makkah, Saudi Arabia, Pilgrims movements during the Hajj is a complex phenomenon which can be defined as a set of prescribed movements of different groups of pilgrims and individuals in the course of performing the religious rituals of the Hajj between Makkah and the holy areas at specific hours on the 8th to 12th days of the pilgrimage month. The Hajj season has witnessed several fatal incidents. In 2006, 340 pilgrims died in a stampede of pilgrims at the stage of the stoning ritual at the Jamarat in Mina, One main cause is the cross-traffic in a high density area. This study investigates characteristics of pedestrian flow during pilgrimage time. Data were collected in one of the high density Streets, the Ayyad Street, Makkah, Saudi Arabia. The aims are to conduct the flow study, and to examine the relationships of pedestrians speed, flow and density

GENERAL APPROACH

Pilgrims movements during the Hajj is a complex phenomenon which can be defined as a set of prescribed movements of different groups of pilgrims and individuals in the course of performing the religious rituals of the Hajj between Makkah and the holy areas at specific hours on the 8th to 12th days of the pilgrimage month add European calendar too (Dhul-Hijja). On the morning of the 10th day of the pilgrimage month, most pilgrims come to Makkah from Mina where they are supposed to remain at Mina from the 10th to the 12th or stay one more day - the 13th of Dhul-Hijja - to stone the devil (Jamarat). During each of these days, pilgrims come to the Holy Mosque at Makkah either to perform Tawaf or to pray. These days, the Hajj season has witnessed several fatal incidents. In 2006, 340 pilgrims died in a stampede of pilgrims at the stage of the stoning ritual at the Jamarat in Mina, in 2004, 251 pilgrims died in a stampede under the feet of pilgrims at the Jamarat. In 2003, 14 people were crushed to death when pilgrims returning from Jamarat. In 2001, 35 pilgrims were killed in the crowd at the Jamarat. In 1998, 118 pilgrims died pilgrims crushed to death after suffering a panic situation on the impact of the fall of some people during the stoning ritual. In 1997, at least 340 pilgrims die after a fire in the pilgrims tents in Mina. In 1994, 270 pilgrims were killed in a stampede during the stoning ritual. In 1990, 1,426 pilgrims were killed in a stampede in an overcrowded tunnel leading to the Holy Mosque in Mecca. (Saudi Civil Defence, 2006). One prime cause is cross-traffic in a highly dense area. Pilgrims finishing the activity leave, or fight their way out, while arrivals to the site, enter, or fight their way in. This type of traffic creates an unpredictable movement pattern which easily results in falling, causing bodily injuries or fatalities. At the seasons of Umrah-Visiting, more than two million persons come to Makkah and Madinah, within a rate of 500.000 persons every month. In the month of Ramadan, this number increases to around three million pilgrims in Makkah. The increasing number of worshippers that come at the same time, and in a specific geographical area, increases the chances of large-scale

disasters. Investigation of Hajj Crowd in Ayyad Street (the main pedestrian pilgrims' walkway to the Holy Mosque) during Hajj time considering the pedestrian characteristics according to raise and ethnic background. This has different crowd dynamics parameters; such as input capacity, speed, flow and density. The input data is obtained by image processing at inlet area at different times during the most populated day during the Hajj in Ayyad Street. The aforementioned parameters are simulated by the SimWalk simulation software which yields the pilgrims crowd characteristics along the path of Ayyad Street. The simulated results are contrasted with a field measured data at selective points along the path. The field video data at selective hours are chosen and the video are decomposed to successive images, and image processing algorithm has been built to recognise and track each individual pilgrim along the course of motion. These field extracted data are used to validate the simulated results in terms of pedestrian flow rate, speed and density. This investigation can be considered as a building block for a comprehensive simulation code including all Hajj activities during the whole period of Hajj. This general simulation could be linked to cameras located at selective places by which an image processing code will interpret those images into an input data to the general simulation program. The simulation results will enable the authorities to diagnose, predict or avoid pilgrims' crowd problems. It is anticipated an overall calibration and validation of this general code is necessary to improve the decision making process.

DATA COLLECTION PLAN

Three data collection exercises were performed in order to collect the necessary information and support an in-depth investigation of the pilgrim crowd dynamics characteristics. For this purpose the following factors were determined:

- Pilgrims' flow rate, speed, and density at Ayyad Street; one of the main roads leading to the Holy Mosque
- Movement patterns of pilgrims e.g. unidirectional, bi-directional, and multi-directional pedestrian flow.
- Pilgrims' density at the Plaza of the Holy Mosque;
- High density spots in front of the main gates of the Holy Mosque;
- Pilgrims demographic characteristics which affect their movement.

In the first phase (2008) a diagnostic measurements of crowd during Hajj time has been collected using still camera. This to help of determine the most critical places which effect the crowd dynamics. In the light of this primary data collection, Ayyad street and the Holy Mosque Plaza have chosen to the case study in the present work. It is anticipated that any better understanding of the crowd dynamics will alleviate the problem of overcrowding

DATA COLLECTION METHODES

Both quantitative and qualitative research methods were used in order to study, analyse, and discuss the pilgrims crowd dynamics at Ayyad street and the Holy Mosque Plaza during the Hajj. A combination of these methods offers full opportunities to study the pilgrim crowd movements from different perspectives. These methods include:

- Video and still image cameras used to collect the pilgrims crowd dynamics from Ayyad Street and the Holy Mosque Plaza.
- Visual inspection of the video recordings and high resolution still images to obtain better understanding of the general mechanisms of how pilgrims interact, (for instance, how they tend to over-take each other, organise themselves into lanes and physically interact with each other) as well as pilgrims crowd trajectories, movement types, and overcrowding spots.
- Extracting the fundamental pilgrim dynamics characteristics; speed, density and flow. by manually

counting.

- Observation of crowd movement patterns during pilgrimage at Ajyad street, and Plaza of the Holy Mosque.
- Statistical analysis of pilgrim's demographic characteristics, e.g. gender, age, and ethnic.
- Computer simulation of pilgrims crowd dynamics during the Hajj season.
- Validation of pilgrim crowd dynamic simulation.

The present data are obtained manually from all video recordings; it proposed to process all video recordings. Footages will be processed a software to obtained the crowd dynamics characteristics at the selected measuring cites of Ajyad street. The software is based on decomposing each video data into their consequential frames. For each frame, the software recognizes each individual pilgrim by detection of its edges or boundaries. A counting algorithm is used to get the crowd density at the time of each frame. Further, image processing of consecutive frames will yield the movement speed for each individual along with the crowd bulk movement. A selected group of individual (pilgrim) will be chosen as a case study to investigate the movement characteristics with respect to place, time and day of event.

Tracking people in crowded scenes

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For the proper understanding and modelling of pedestrian dynamics, reliable empirical data is necessary for analysis and verification. Collecting the trajectories of every person with a high temporal and spatial resolution allows a detailed analysis of movement and the calibration and verification of microscopic models in space and time [Steffen2011, Chraibi2010].

In recent years we have performed an extensive series of well-defined experiments with up to 350 people to study the movement of pedestrians in different situations [Seyfried2010, Holl2009]. These laboratory experiments give us the opportunity to analyse parameters of interest under controlled conditions. The variability allows a survey of a parameter range e.g. for the bottleneck width or length, or the density inside a corridor. Parameters, like the density, can be set to values seldom seen in field studies (e.g. very high densities). For such experiments the characteristics of the test persons (e.g. culture, fitness, age, gender, body height) can be determined.

For the analysis of these experiments we have developed a software to automatically extract trajectories from video recordings of marked people on plane ground [Boltes2010] and uneven terrain [Boltes2011]. The program is able to handle lens distortion and high pedestrian densities. For experiments e.g. at stairs but also for experiments on plane ground stereo recordings are needed to get spatial trajectories and to take the perspective distortion into account.

Despite the above mentioned advantages the experiments under laboratory conditions have also drawbacks. The number of experiments is limited due to the costs of the test persons and for building the artificial environments. Thus the variance of the studied parameter is limited. Also the combination of differences inside a detected group cannot be covered by laboratory experiments.

Therefore we present a new approach to detect pedestrians without marker also in crowded scenes to facilitate field studies and the easier realization of moderated experiments in real environments. The newly introduced method based on the analysis of the depth field of stereo recordings taken from overhead of the pedestrians. The overhead recordings perpendicular to the floor allow a view without occlusion for a range of body heights, so that a microscopic detection and tracking without estimation of the persons' route can be performed.

There has already been done a lot of work in the field of pedestrian detection. Most of the approaches are for monocular cameras and slanted views like from surveillance cameras, and densities which result only in temporary or partly occlusion. One of the best results for these scenarios can be found in [Schwartz2009]. Existing techniques for trajectory extraction for stereo cameras, such as

[Harville2004], depend on accurate segmentation of foreground objects. For dense crowds such as in our experiments these methods are not applicable or could only detect groups of people.

Our extraction method copes also with crowded scenes. It directly uses the perspective depth field, and does not use laborious plan-view statistics to speed up and simplify the extraction step. The depth field contains the distance to the camera for every pixel and is inversely proportional to the disparity map, which describes the pixel offset of both camera view fields of the stereo camera for every pixel.

The new method works now as follows. The identification of the people is done only using the shape of the top part of their body especially the head and shoulders. If we want to identify people only by their shape, a background subtraction has to be performed before to reduce the number of false positive detections. Pixels are part of the background and thus are ignored in the detection process, if the distance to a perspective depth field of the background is smaller than a threshold value. The perspective depth field of the background is set once with the scene deserted or is set to a cautiously adapted maximum distance during all frames.

To identify pedestrians by means of the depth field we determine directed isolines of the same distance to the camera at equidistant depth levels for the upper body part. In advance the depth field is adapted by replacing values covered by the background mask with the furthest value belonging to the foreground.

The isolines enclosing a minimum and maximum of pixel and with a small ratio between the length of the isoline and the enclosed area (to eliminate isolines with big dents) are approximated by ellipses. The ellipses allow an easier access to the global shape. By scanning the depth field from the head downwards a pyramid of ellipses for the upper body part of every person is build up. These measured peoples' pyramidal ellipses stacks (PES) are matched against a variance of people models where the perspective view has to take into account. The PES are compared to ellipses stacks we generate of synthetic models by raytracing a virtual scene simulating the depth sensing of a stereo camera.

The PES resulting from a measured disparity map are unstable and thus the centre of the top most ellipse is not a good point for the centre of the head. To stabilize the procedure and thus to get smoother trajectories we utilize the distorted axis of the PES for a more settled centre. The smoothness of trajectories resulting from people detection with and without marker is compared in the paper, because it is important for further analysis (e.g. instant velocity) of the trajectory data.

A strict rejection of not proper fitting PES avoids false detections since it is not necessary for tracking to detect a person every frame. For tracking the pedestrians the robust pyramidal iterative Lucas Kanade feature tracker is used to join the same detected pedestrian in successive frames or bypass over frames where a specific pedestrian could not be located.

The tracking results exceed the results of all former methods for tracking of markerless pedestrians. Besides this, the markerless detection can improve the robustness of the marker based detection, as detected marker not lying on an elevation describing a persons' head can be rejected.

REFERENCES

- [Boltes2010] M. Boltes, A. Seyfried, B. Steffen, and A. Schadschneider. *Automatic Extraction of Pedestrian Trajectories from Video Recordings*. In: [PED2008], 43–54.
- [Boltes2011] M. Boltes, A. Seyfried, B. Steffen, and A. Schadschneider. *Using Stereo Recordings to Extract Pedestrian Trajectories Automatically in Space*. In: [PED2010], 751–754.
- [Chraibi2010] M. Chraibi, A. Seyfried, and A. Schadschneider. *Generalized centrifugal force model for pedestrian dynamics*. *Physical Review E*, 82:046111, 2010.
- [Holl2009] S. Holl and A. Seyfried. *Hermes - an Evacuation Assistant for Mass Events*. *inSiDe*, 7(1): 60–61, 2009.
- [Harville2004] M. Harville. *Stereo person tracking with adaptive plan-view templates of height and occupancy statistics*. *Image and Vision Computing 22, Statistical Methods in Video Processing*, 127 – 142, 2004.
- [PED2008] W. W. F. Klingsch, C. Rogsch, A. Schadschneider, and M. Schreckenberg (ed.), *Pedestrian and Evacuation Dynamics 2008*, Springer, 2010.
- [PED2010] R. D. Peacock, E. D. Kuligowski, and J. D. Averill (ed.), *Pedestrian and Evacuation Dynamics 2010*, Springer, 2011.
- [Schwartz2009] W. R. Schwartz, A. Kembhavi, D. Harwood, and L. S. Davis. *Human Detection Using Partial Least Squares Analysis*. *International Conference on Computer Vision (ICCV 2009)*, Kyoto, Japan, 2009.
- [Seyfried2010] A. Seyfried, M. Boltes, J. Kähler, W. Klingsch, A. Portz, T. Rupperecht, A. Schadschneider, B. Steffen, and A. Winkens. *Enhanced empirical data for the fundamental diagram and the flow through bottlenecks*. In: [PED2008], 145-156.
- [Steffen2011] B. Steffen, M. Boltes, and A. Seyfried. *Improved Methods for Checking Forces Based Models of Pedestrian Dynamics*. In: [PED2010], 885–888.

Using a multi-scale model for simulating pedestrian behavior

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Simulation of crowd dynamics has become an important field of research in the last years. A variety of different approaches have been developed according to different objectives. These approaches model crowd behavior on different scales: Small scale models, like cellular automata (Blue & Adler 1999) or social force models (Helbing & Molnár 1995), model each individual and move these individuals to a set of rules, until all individuals have reached designated destination..On the small scale objective pedestrians typically steer directly towards a visible target trying to avoid other pedestrians.

Secondly, medium-scale models consider slightly more complex navigation behavior typically not steering directly towards a destination, e.g. if the destination lies behind an obstacle. Typically, this medium scale navigation behavior is combined with an appropriate small scale model. As for the small scale models pedestrian behavior can be modeled effectively using potentials or forces given as gradients of potentials. By moving along the gradient of these potential fields, pedestrians steer towards the desired destination, since it is located in the minimum.

Finally, there exist large-scale models, which consist of networks or graphs. These data structures are used to apply routing algorithms to guide pedestrians through a graph or network in order to reach a certain destination. An example for such models is a network optimization model (e.g. Hamacher & Tjandra 2002).

In this contribution, a combination of all three different scales is discussed. We believe that modeling pedestrians' behavior is complex and needs to consider different levels of detail. In our multi-scale model, the microscopic layer forms a cellular automaton, which consists of hexagonal cells. In each time step, each pedestrian can occupy exactly one cell. By applying certain update rules in each update step, which are derived from the small scale layer (avoiding other pedestrians) and the medium-scale layer (navigation towards the destination), each pedestrian is moved to a free neighboring cell, which is located closer to the destination. Potentials or so-called navigation fields are used to model the medium-scale layer. By assigning repellent forces to obstacles and other moving pedestrians, a navigation field can be generated, which contains the shortest path to the destination. Using the Fast Marching Method (Sethian 1999), these fields can be created very efficiently on top of regular grids – which in this case are the dual grids of the cellular automaton. The basic idea is to propagate a wave, which slows down when passing obstacles and gets faster around these. Now, pedestrians are able to walk on the fastest path from the source to their destination. This combination between small-scale and medium-scale layers has been implemented within many simulators, e.g. (Kretz 2009), (Köster, Hartmann & Klein 2010) or (Nishinari et al. 2004).

In contrast to the assumptions taken in the models described above, not always the shortest path is chosen by pedestrians considering real-world behavior. Additionally to considering other moving pedestrians in the direct vicinity (as adopted by many existing approaches), other pedestrians are considered as well on the large-scale layer. This layer is implemented by a navigation graph, i.e. visibility graph, which is derived directly from the topography of a given scenario (Kneidl, Borrmann & Hartmann 2011). Using this graph, first of all, different types of way-finding behaviors like following the fastest path, following signage, avoid congestions can be modeled by applying different routing algorithms. For all these algorithms, edge weights have to be defined in order to measure different routes through such a graph. Edge weight derivation hereby can be done in different ways: The simplest would be to take the distance between two adjacent vertices. This does not take into account any other moving pedestrians. A second possibility is to use instead travel times. Since the velocity of pedestrians depends on the density of a crowd, the travel time increases if an edge becomes more crowded.

However, deriving densities on edges is ambiguous. Steffen & Seyfried (2010) propose methods to derive local densities. With cellular automata, pedestrians in neighboring cells can be counted efficiently. Still, these measures are estimates, since the corresponding velocity is an estimated value itself corresponding to (Weidmann 1993).

To overcome these issues, we propose to use navigation fields (sometimes called floor fields) from the medium-scale layer and estimate from these travel times on each edge. The considered navigation fields are dynamic with respect to existing pedestrians, as proposed by (Hartmann 2010), and are updated if a certain event on an edge occurs. Instead of having only one large navigation field for the whole scenario, whose update would be computationally very intensive if a large scenario is simulated, we define many small fields. These small fields are constructed by connecting two adjacent vertices of the large scale navigation graph, i.e. intermediate destinations. This results in defining one navigation field for each edge. With these small fields, the update can be calculated very efficiently. In addition, we can directly retrieve the edge weight by simply taking the value of the cell of the start node of an edge, since we construct the navigation field propagating the wave from the end node to the start node. The value thus refers to the detour a pedestrian has to take in order to evade all other moving pedestrians. This is a more precise measure for the edge weights, since it is directly read from a given situation and not estimated through assumption as before.

In our contribution, we will outline the exact setup of our multi-layer simulation model, including a detailed description of each layer and their interaction. The increase in realism as well in as in computational performance will be underlined by ostensive examples.

REFERENCES

Blue, V and Adler, J 1999, 'Cellular Automata Microsimulation of Bidirectional Pedestrian Flows', *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1678, pp. 135–141.

Hamacher, HW and Tjandra, SA 2002, 'Mathematical modelling of evacuation problems: A state of the art' in *Pedestrian and Evacuation Dynamics. International Conference on Pedestrian and Evacuation Dynamics, held at the Gerhard-Mercator-University Duisburg, Germany, April 4 - 6, 2001; with 28 tables*, ed M Schreckenberg, Springer, Berlin, pp. 227–266.

Hartmann, D 2010, 'Adaptive pedestrian dynamics based on geodesics', *New Journal of Physics*, vol. 12, no. 4, p. 43032.

Helbing, D and Molnár, P 1995, 'Social Force Model for Pedestrian Dynamics', *Physical Review E*, vol. 51, no. 5, pp. 4282–4286.

Kneidl, A, Borrmann, A and Hartmann, D 2011, 'Generating sparse navigation graphs for microscopic pedestrian simulation models'. *Proceedings of the 2011 eg-ice Workshop*, eds T Hartmann, P de Wilde and Y Rafiq.

Köster, G, Hartmann, D and Klein, W 2010, 'Microscopic pedestrian simulations: From passenger exchange times to regional evacuation'. *Operations Research - Maturing complexity*.

Kretz, T 2009, 'Pedestrian traffic: on the quickest path', *J. Stat. Mech.*, vol. 2009, no. 03, pp. P03012.

Nishinari, K, Kirchner, A, Namazi, A & Schadschneider, A 2004, 'Extended floor field CA model for evacuation dynamics', *IEICE Trans. Inf. Syst*, E87D, pp. 726–732.

Sethian, JA 1999, *Level Set Methods and Fast Marching Methods*, Cambridge University Press.

Steffen, B and Seyfried, A 2010, 'Methods for measuring pedestrian density, flow, speed and direction with minimal scatter', *Physica A: Statistical and Theoretical Physics*, vol. 389, no. 9, pp. 1902–1910.

Weidmann, U 1993, *Transporttechnik der Fussgänger. Transporttechnische Eigenschaften des Fussgängerverkehrs (Literaturauswertung)*, ETH Zürich.

On the simulation for rail tunnel evacuation with cross-passageways

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Accidents in rail tunnels cannot be seen very often by comparing with disasters such as building fires. But once it happens the damage is always unpredictable and unacceptable. It has been reported in the book “The handbook of tunnel fire safety” [1] that hundreds of serious tunnel fires had caused the loss of tens of thousands of lives during the past few decades. To study the nature of evacuation from rail tunnels is essential for reducing the human life lost in a rail tunnel accident. There has already been an extensive literature on the research of fire safety in tunnels, but most of them have been focused on the nature of fire incidence, not the evacuation process. Oswald et.al. [2, 3] have presented their studies about the evacuation in tunnel fire situations by experiments in the past PED conferences. But simulation works on this topic is still very rare.

It is denoted in the NFPA (National Fire Protection Association) 130 standard (Standard For Fixed Guideway Transit and Passenger Rail Systems) [4] that “The system shall incorporate a walk surface or other approved means for passengers to evacuate a train at any point along the trainway” and that “within underground or enclosed trainways, the maximum distance between exits shall not exceed 762 m”. Then cross-passageways or exit stairs are essential for a tunnel longer than 762m, especially for twin tunnels. It also denotes that the means of egress within the trainway shall be provided with the minimum clear width of 610mm at the walking surface level and cross-passageways with a minimum clear width of 1120mm shall not be farther than 244m apart. But the real situations in engineering projects are more complex and sometimes need further performance-based evaluations. In order to figure out the effects of different dimensions of the tunnel egress elements, to build a reliable simulation model eligible for tunnel egress cases will certainly be the first concern. But egress from tunnels is still a challenging topic considering that the special narrow and confined space, the complex interactions between people and people, etc.. The volume of publications for studying egress process from rail tunnels, especially the computer simulation studies, is limited.

In the past many years, large amount of computer simulation models for pedestrian and evacuation dynamics in various environments and situations have been developed. Benefiting from the development computer technology, microscopic models are becoming more and more popular recently. Microscopic models are usually considered be divided into discrete models and continuous models. Discrete models, such as the Cellular Automaton (CA) model, the Lattice Gas (LG) model, etc. usually discretize the floor plan into uniform rectangular grids. Each grid represents a certain dimension of space in reality, such as $0.5 \times 0.5 \text{m}^2$, and can either be occupied by at most one person or be vacant. Discrete models are popularly used in many evacuation and pedestrian flow simulation software because of its high computing efficiency. But the feasibility of using discrete models for the narrow passages or very confined areas such as the walkway inside a tunnel should be further

examined because the narrow walkways in tunnels are difficult to be expressed by “grids”. For example, the 610mm and 710mm width walkway will be the same in a discrete model since both of them will become one grid width in the simulation.

Continuous models usually employ forces between people and people, people and environment, to governing the movement from the perspective of physics. The continuous models suffer from low computing efficiency and are not easy to be applied for practical use, especially for cases where large number of people is involved. But they allow people to move continuously in the simulation domain in all the directions and thus their simulation results may be closer to reality in simulating detailed pedestrian moving trajectories and patterns. It is very likely that the continuous models could get better results than discrete models on modeling cases with narrow passages or environments with very confined area (where how the space is represented becomes important to the results). But report on this topic is very rare.

In this study, an agent-based continuous crowd simulation model is developed to study the features of tunnel evacuation. The 2D floor plan is defined by points and lines and the human body is represented as an agent with movement direction, awareness angle and awareness distance. The model is implemented in two levels: first, the macroscopic level for route choice and road map navigation; second, the microscopic level for agent movement and obstacle avoiding. The governing rules for agent movement are designed by considering several factors, including the efficient of approaching the intermediate target position, the agent’s obstacle avoiding behavior, the interactions triggered by the change of distance and moving direction between different agents. The model is able to move agents in any direction in continuous space, thus enable us to handle the minor changes of tunnel egress elements’ dimensions such as a 100mm’s increase of walkway width.

By referring to these standards stated in NFPA 130, evacuation from rail tunnel with cross-passageways is studied by simulations with the agent based model. This study is focusing on the egress time and the pattern of the crowd flow dynamics under different tunnel egress element dimensions or scenarios. Simulations for different scenarios are conducted to examine the influence of the different walkway width W and cross-passageways spacing S on the evacuation results. Two scenarios, scenario A and B are setup to study the influences of W and S , correspondingly. In scenario A the value of S is fixed and the value of W varies from 610 mm to 1610 mm, while in scenario B the value of W is fixed and the value of S varies from 60 m to 294 m. Both scenarios A and B are simulated by the two kinds of models. Besides, given that different emergency alighting positions of the train may lead to different relative locations of the train doors to the cross-passageways. Thus, different evacuation strategies are examined and discussed based on the simulation results in this study. The interactions between the fore and after agents within the queue on the narrow walkway and the flow patterns under situations with different walkway dimensions are also interesting problems to be presented in this study.

REFERENCES

[1] Carvel, R. and G. Marlair, *A history of fire incidents in tunnels*, in *The handbook of tunnel fire safety*, Alan Beard and R. Carvel, Editors. 2005, Thomas Telford: Heron Quay, London. p. 3-37.

[2] Oswald, M., H. Kirchberger, and C. Lebeda, *Evacuation of a High Floor Metro Train in a Tunnel Situation: Experimental Findings*, in *Pedestrian and Evacuation Dynamics 2008*. 2008. p. 67-81.

[3] Oswald, M., et al., *Full-Scale Evacuation Experiments in a smoke filled Rail Carriage — a detailed study of passenger behaviour under reduced visibility*, in *Pedestrian and Evacuation Dynamics 2005*. 2007. p. 41-55.

[4] NFPA, *NFPA 130-Standard For Fixed Guideway Transit and Passenger Rail Systems 2010 Edition*, in *Chapter 6 Trainways*. 2009: Batterymarch Park, Quincy, MA.

Investigating human factors in fire evacuation – a serious-gaming approach

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A new way to reach fire safety design decisions is presently being established as an alternative to the use of prescriptive codes: the performance-based approach. This process started a few years ago driven by the ISO [1]. Applying the performance-based approach to fire protection design emphasizes the safe performance of a building as a whole rather than meeting detailed code requirements. To this effect, fire safety engineers make use of computer models and simulations to describe the expected spread of fire and smoke, and the safety evacuation itself [2]. Since the protection of human life is the primary aim of the performance-based approach, the predicting the behavior of people in danger is an essential purpose of such modeling. Particularly, the relevant human factors (individual decisions and parameters to describe human behavior) have to be taken into account. According to Santos and Aguirre [3], for an evacuation simulation, three analytical dimensions need to be considered: the built environment (physical location), the management of this environment (signage, escape routes), and psychological and social-organizational characteristics of the occupants. Tavares [4] pointed out that an evacuation simulation model must consider four interactions: occupants-structure; occupants-occupants; occupants-fire (in case of fire events) and fire-structure (for this purpose, a fire model should be used).

To examine these human factors different data-collection techniques like interviews with survivors, online questionnaires, map exercises or simulation experiments are used. These methods often cover only singular aspects of human behavior or studies are carried out independently from each other. Another point is that interviewees mostly know that they are not in a dangerous situation and therefore feel no cognitive emergency stress. However, in the FSE community there is some controversy about this point. Santos and Aguirre [3] argue that appropriate methods for validation of the human behavior model are not available. So they state that proper validation tools have to be developed and that therefore multidisciplinary collaboration is needed. However, according to them, the ability to accurately and comprehensively simulate human behavior is missing from current computer evacuation models [3]. According to Kuligowski and Gwynne [5] these models often have the problem that the behavior simulated in the scenario is actually prescribed by the user (with probabilistic assumptions based on collected data) rather than predicted by the model and that the current models are only simulating separated behavioral facts. This shows there is need for a new method to validate existing human behavior models and for analyzing human behavior in extreme building evacuation situations.

The aim of the presented research is thus to achieve a better understanding of what actually happens during an extreme situation and how people come to decisions within a serious gaming approach. The research hypothesis to be examined is: Can human evacuation behavior be explored using a

computer game? While playing a game „real“ people rather than software agents will have to slip into the role of the evacuees. To implement this approach, the challenge is to develop a realistic and valid serious game for a new kind of immersive, dynamic and interactive simulation of building disasters. To address the presented hypothesis, scientists at the Institute of Numerical Methods and Informatics in Civil Engineering (IIB) and at the Institute of Psychology at Technische Universität Darmstadt are working together in a multidisciplinary project team. For this research, the interaction occupant-building structure is of particular interest because this cannot really be investigated by real world experimentation. But creating realistic game scenarios is still time-consuming, because of the large amount of modeling work that has to be performed twice (e.g., 3D-modeling): first by the architect for the parametric building model as part of traditional building planning, and a second time by the game artist generating the 3D-game content.

The challenges are, firstly, to model the game scenario based on parametric building objects (geometry, structure and further technical semantic out of real building designs), and, secondly, to enhance the model with an authentic simulation of the emergency scenario (e.g., fire, smoke, explosions). To make sure that the model is valid, it is essential that the simulations are comparable to state-of-the-art fire safety engineering simulations. At this point domain-specific knowledge especially from the field of civil and fire safety engineering is required. One possibility is to retrieve this knowledge from the Building Information Modeling (BIM) process by using it as a „knowledge repository“. Researchers at IIB are developing new methods for bringing BIM and serious gaming together for an automatic generation of the game scenario out of the BIM. Another challenge is to stimulate an immersive experience in the gamer. This is important to improve the presence of the gamer inside the computer game. Generally, virtual environments vary greatly in the quality of representing the real world. It is plausible to assume that the more accurate and richly detailed the real-world is mapped onto the virtual-world, and the more the senses can be adequately stimulated, the more the immersive effect of a virtual environment will increase. To test these assumptions, scientists from the Institute of Psychology are currently conducting initial experiments regarding the stereo image capabilities, sound effects and human interface devices (HID) in the context of this project to find optimal hardware settings. The senses to be considered in principle are hearing, touch, smell, taste, and sight. In order to minimize unrealistic behavior in the virtual world, the gamer should have the feeling to be physically inside the virtual world. Playing computer-games, gamers often tend to make unrealistic decisions due to lack of physical pain and injury responses from the virtual world. This is known in military training as the „super-soldier syndrome“ [6, 7]. Therefore strategies have to be developed to avoid this effect and to ensure that gamers do not consider themselves to be invulnerable „super-evacuees“.

The paper introduces the concept of a new kind of a BIM-based serious game, for an interactive and real-time simulation of emergency scenarios. This has the potential to provide a new method for data collection and validation in the area of evacuation simulations.

REFERENCES

[1] ISO TC 92 (2002). *Res.244 TG N6 Framework for the long term standardization of fire safety in support of performance-based design*.

[2] Friedman, Raymond, (1992) *An International Survey of Computer Models for Fire and Smoke SFPE Journal of Fire Protection Engineering*, 4 (3), 1992, p. 81-92 Available online: <http://www.firemodelsurvey.com> last accessed May 2011

[3] Santos G. Aguirre, B.E. (2004). *A Critical Review of Emergency Evacuation Simulation Models*. In *NIST Workshop on Building Occupant Movement during Fire Emergencies*

[4] Tavares, R.M. (2008). *Evacuation Processes Versus Evacuation Models: „Quo Vadimus“?*, *Fire Technology* 2008, ISSN-1572-8099

[5] Kuligowski, E.D.; Gwynne, S., (2010) *The Need for Behavioral Theory in Evacuation Modeling*, in *Pedestrian and Evacuation Dynamics 2008* Isbn: 978-3-642-04504-2, Springer Berlin Heidelberg

[6] Barlow M. And Morrison, P., (2005). *Challenging the Super Soldier Syndrome in 1st Person Simulations*, Available online: www.siaa.asn.au/get/2411856229.pdf, Last accessed: May 2011

[7] Morrison, P., Barlow, M., Bethel, G. And Clothier, S., (2005). *Proficient soldier to skilled gamer: training for COTS* Available online: http://seal.tst.adfa.edu.au/research/vesl/Papers/Training4COTSSuccess_simtect05.pdf Last accessed: May 2011

Validation and calibration of the EXIT89 evacuation model for road tunnel evacuation applications

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Computational Modelling software has been used in recent years as a tool for analysing the occupants' safety condition in case of emergency in ever more complex infrastructures. This is the reason why their application - initially almost exclusively for buildings - is currently extended to a large number of environments, including underground spaces. Road tunnels are unique environments with their own specific characteristics: unknown to users, no natural light, etc., which affect different aspects of Human Behaviour such as pre-evacuation times (e.g. people may show vehicle attachment), occupant-occupant and occupant-fire interactions, herding behaviours, exit selection, etc. [Boer, 2003 and Shields and Boyce, 2004].

The validation of an evacuation model is generally performed through testing its predictive capabilities within a set of standard environments (e.g. buildings) or standard layouts such as the IMO tests (IMO, 2007). Unfortunately, non-expert users could consider model results as reliable in unique environments as well, and extend their use to applications where no ad hoc validation tests have been performed. The use of a model beyond its validation evidence requires then an additional effort by the evacuation modeller to understand the model limitations in representing the evacuation process in that specific environment.

This paper focuses on the applicability of the EXIT89 evacuation model for road tunnel evacuations. EXIT89 is a network-based model able to simulate the evacuation of large populations through complex infrastructures like high-rise buildings. The model permits the simulation of different aspects related to human performance under fire conditions, such as travel paths, delay times, merging flows, counter-flows, etc. Travel speeds are considered within the model as a function of the changing crowdedness of spaces during the evacuation [Fahy, 1996 and 2001, ISO document 2011]. Walking speeds are then calculated in accordance with people density as well as occupant characteristics, using the equations provided by Predtechenskii and Milinskii [1978]. Road tunnels are environments where low occupant load may often occur during evacuations, except for mixed-used tunnels (i.e. pedestrians and vehicles) where high densities can easily arise [Ronchi et al., 2010]. The crucial factors during an evacuation scenario could then be related to the occupants' behaviour during the pre-evacuation phase more than on the people movement itself [Purser, 2009]. Thus, there is a need of testing the predictive capabilities of models where speeds are based on people density (e.g. EXIT89) for the specific case of road tunnel evacuation scenarios.

The first part of the paper is a validation exercise for road tunnel applications. The predictive capabilities of EXIT89 are tested by comparing the model results with the tunnel evacuation experiment performed by the Department of Fire Safety Engineering and System Safety of Lund

University in 2006 [Nilsson et al., 2009] in the Göta tunnel in Göteborg. Participants were partially informed during the experiments i.e. they were only told they were taking part in a study about driving behaviour, thus permitting the analysis of participants' behaviours in case of an unannounced evacuation. Results show that the model is able to reproduce the evacuation process, although a high degree of modeller's expertise is required for accurately calibrating the model input in case of low occupant load. The representation of the tunnel environment is done by simulating different parts of the tunnel through a network of nodes. Thus modellers need to calibrate the correct dimensions of nodes to take into account the fact the model is not reproducing separated rooms as in case of building environments.

The second part of the paper is a case study of an Italian road tunnel, the Condò tunnel in Lecce. It is a two-bore road tunnel with an emergency link tunnel between the two bores. It belongs to the Trans-European Network that in Italy is under the management of the Italian Company of Roads (ANAS Azienda Nazionale Autonoma delle Strade). The predictive capabilities of EXIT89 were used to analyse different scenarios in which a set of different variables affecting the evacuation process were varied i.e. visibility conditions, initial walking speeds, occupant load, etc.

In particular, the purpose of this case study is to evaluate how different starting visibility conditions would affect the final evacuation times. This is done by assuming different extinction coefficients within the tunnel representing different degrees of severity of the occurred accidents. Initial walking speeds are then simulated by applying the correlation between extinction coefficients and walking speeds provided by Jin [1970]. Results provide information on the evacuation process (e.g. merging flows, occupant densities in the nodes during the passage of time, etc.) and subsequent evacuation times in relation to the assumed visibility conditions. EXIT89 results are compared with the results produced by the capacity method provided in the Society of Fire Protection Engineering Handbook [Gwynne and Rosenbaum, 2008]. Particular attention is paid to the differences among the two methods employed for scenarios considering a low occupant load.

Conclusions focus on model strengths and limitations in the reproduction of human behaviour aspects related to road tunnel evacuations. Considerations to improve the reliability of the model results are provided as well.

REFERENCES

[1] IMO (2007), *Guidelines for Evacuation Analyses for New and Existing Passenger Ships*, MSC/Circ.1238, International Maritime Organization, London, UK.

[2] Fahy, R. F. (1996) *Enhancement of EXIT89 and analysis of World Trade Center data*, NIST-GCR-95-684, Fire Analysis and Research Division.

[3] Fahy, R. F. (2001), *Update on the Features and Demonstrated Predictive Capability of EXIT89*. *Engineered Fire Protection Design. Applying Fire Science to Fire Protection Problems*, International Conference. *Proceedings*. Co-organized by: Society of Fire Protection Engineers (SFPE) and National Institute of Standards and Technology (NIST). June 11-15, 2001, San Francisco, CA, pp. 303-314.

[4] ISO/TC 92/SC 4 N622 (2011) *Fire Safety Engineering – Example on verification and validation of a calculation method – Part 4: Egress model*.

- [5] Predtetschenski W.M., and Milinskii, A. L., (1978) *Planning for foot traffic flow in buildings*, Amerind Publishing, New Dehli.
- [6] Boer L. C., (2003) *Behavior of Drivers during Tunnel Evacuation. (Re)Claiming the Underground Space (pp 213-217)* J. Saveur, Lisse, The Netherlands.
- [7] Shields T. J., Boyce K., (2004) *Towards Developing an Understanding of Human Behaviour in Fire in Tunnels. Proceedings of 3rd International Symposium Human Behavior in Fire*, Belfast, UK pp215-228.
- [8] Purser, D. A. (2009) *Application of human behaviour and toxic hazard analysis to the validation of CFD modelling for the Mont Blanc Tunnel fire incident. Proceedings of the Advanced Research Workshop: Fire Protection and Life Safety in Buildings and Transport systems University of Cantabria, Spain. 15-17 October 2009.*pp 23-57.
- [9] Ronchi, E., Alvear, D. Berloco, N., Capote, J. Colonna, P., Cuesta, A.: (2010) *Human Behaviour in Road Tunnel Fires: Comparison between Egress Models (FDS+Evac, STEPS, Pathfinder)*, *Proceedings of INTERFLAM2010*, pp. 837-848 Nottingham, UK.
- [10] Nilsson, D., Johansson, M., & Frantzich, H. (2009) *Evacuation experiment in a road tunnel: A study of human behaviour and technical installations. Fire Safety Journal*, 44(4), 458-468.
- [11] Jin, T. (1970) *Visibility through Fire Smoke*, *Bull. of Japanese Assoc. of Fire Science & Eng.*, 19, 2, pp. 1-8.
- [12] Gwynne, S. M. V., Rosenbaum, E. (2008) *Employing the Hydraulic Model in Assessing Emergency Movement. SFPE Handbook of Fire Protection Engineering, 4th Edition. National Fire Protection Association, Quincy, MA.*

Poster exhibition

Unsorted list

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Simulation of bidirectional pedestrian flow through a channel with a bottleneck

Alessandro Corbetta, Politecnico di Torino, Torino ITALY

Multi-scale non-local first-order modelling of crowd dynamics: a general framework with application to footbridges

Majed Almejmaj, Worcester Polytechnic Institute, Worcester MA USA

Observations from student exercises and proposed experimental scenarios for human behavior data collection

Minjie Chen, Technische Universität Berlin, Berlin GERMANY

Simulation of pedestrian dynamics with density control on a regular grid

Kongjin Zhu, University of Science and Technology of China, Hefei CHINA

The non-symmetrical choice behavior during evacuation experiments in building with multi-obstacle

Georg Walenciak, Universität Heidelberg, Heidelberg GERMANY

Agent-based modelling and evacuation simulation for disaster preparedness and management

Vaisagh Viswanathan, Nanyang Technological University, Singapore SINGAPORE

An information-based model of pre-evacuation behavior for agent based egress simulation

Masatoshi Kaitsuji, Kobe University, Kobe JAPAN

Venue suitability for large-scale events from the standpoint of crowd safety

Simulation of bidirectional pedestrian flow through a channel with a bottleneck

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Bidirectional pedestrian flows through a channel have been investigated numerically by many researchers in recent years. Several experiments on the unidirectional flows passing a bottleneck have been performed and some experimental data are available to calibrate these simulation models for pedestrians.. Tajima et al. investigated the unidirectional pedestrian flow through a channel with a bottleneck by the lattice gas model. However, similar problems for pedestrian counterflow have been seldom investigated either experimentally or numerically, especially by discrete microscopic models, e.g. lattice gas model and cellular automata model. Due to the existence of the bottleneck, it is easy to form congested area on both side of bottleneck even at rather low densities without efficient interactions during simulations. Helbing et al. carried out several experiments for counterflow in a channel with bottlenecks, which is for comparison with unidirectional flow, and which exclusively indicated many self-organized phenomena, such as lane formation. These phenomena were also reproduced by adopting the social force model. Burstedde et al. proposed a cellular automata model to reproduce collective phenomena by introducing floor field inspired by trail formation models such as lane formation and the oscillations of the direction of flow at bottleneck. However, these results are reported in a very simple manner. Hereafter, few works have been done to support or improve these findings in the context of cellular automata models.

The present paper simulates the bidirectional pedestrian flow through a bottleneck at the middle of the channel under periodic boundary conditions. The model used here is the extension of the cellular automata model for pedestrians based on the floor field that was proposed by Burstedde and Schadschneider. The bottleneck can be viewed as an obstacle, thus the distance in the static floor field is not simply taken as that between a pedestrian's current position to the target. The method suggested by Huang is adopted to obtain the static field which calculates the distance of the shortest path to the target without considering pedestrians. Two static floor fields are generated for the right and left walking pedestrians, respectively. As a consequence, a pedestrian is driven by the static floor field and walk towards his target. Here, the pedestrian is only permitted to move in four directions, i.e., right, left, up and down. According to the static field and the states of neighboring cells, one can calculate the matrix of transition probabilities of the pedestrian by the method suggested by Schadschneider. In addition, the visual field is introduced to represent the dynamical effect generated by pedestrians which enlarges the interaction region between pedestrians. The scope of visual field is a rectangle area of size $m \times 2n + 1$, i.e. the size of the right, front and left visual fields are $m \times n$, $m \times 1$ and $m \times n$ respectively, where m is the length of the visual field and n the width of the right or left visual field. These pedestrians of both the same and opposite directions in the visual field of a pedestrian are taken into account. And three transition probabilities in the visual field are modified accordingly. The visual field reduces the number of encounters with oppositely moving pedestrians and strengthens the tendency to follow

preceding pedestrians with the same direction. Therefore, the movement of a pedestrian is determined by the modified matrix of transition probabilities. The parallel updating rules are used during the simulation. One should deal with collisions among pedestrians, i.e., several pedestrians may enter the same target cell simultaneously. Then they are set to have equal probability to do so. At the beginning of each simulation, pedestrians are randomly distributed at a given density in the channel.

Numerical simulations are performed to draw the following conclusions: (1) It is found that both the saturated flow rate and the critical density increase with the bottleneck width W_d . For a given bottleneck width, the average velocity decreases with the density. A dynamical phase transition occurs from the free flow to the choking flow. (2) The effect of the sensitivity parameter K_s for static floor field is investigated. It turns out that the saturated flow rates are nearly the same when K_s is greater than or equal to one. While one takes smaller value of value, pedestrians have no strong intention to pass the bottleneck and lead to a lower saturated flow rate. The critical density decrease with the sensitivity parameter K_s . It means that congestion at bottleneck occurs at lower densities if pedestrians have stronger intention to pass the bottleneck (i.e. "faster-is-slower"). (3) The size of the scope of visual field is studied. It is shown that both the saturated flow rate and the critical density increase with the length of visual field m , however, the width of visual field has negligible effect. If the visual field is not considered, the saturated flow rate is much lower than that with visual field as well as the critical density. The visual field plays a vital role in enhancing the efficiency of local interactions among pedestrians. (4) Different ratios of two groups with opposite directions is investigated and found that both the saturated flow rate and the critical density have not changed significantly but the asymmetrical case enhance the flux when the density is larger than the critical density. (5) The snapshot of a simulation with $\rho=0.1$, $W_d=5$ shows the separation of two groups of opposite directions passing the bottleneck into two separate lanes after long enough simulation. But at a high density $\rho=0.2$, pedestrians build up on both side of the bottleneck and form a congested area. However, this area is not fully compact so that few pedestrians can release from it. Usually, such a process is intermittent, therefore it can not be regarded as the typical oscillations at bottlenecks. In summary, the visual field is introduced to the cellular automata model based on the floor field, which enhance the efficiency of local interactions and avoid unnecessary collisions significantly. Therefore, the improved model can give a better description of pedestrian counterflow through a bottleneck in a channel.

REFERENCES

- M. Muramatsu M, T. Irie and T. Nagatani, *Jamming transition in pedestrian counter flow*, *Physica A* 267, 487-498 (1999)
- T. Kretz, A. Grünebohm and M. Schreckenberg, *Experimental study of pedestrian flow through a bottleneck*, *Journal of Statistical Mechanics: Theory and Experiment*, P10014 (2006)
- Y. Tajima, K. Takimoto and T. Nagatani, *Scaling of pedestrian channel flow with a bottleneck*, *Physica A* 294, 257-268 (2001)
- D. Helbing and P. Molnár, *Social force model for pedestrian dynamics*, *Physical Review E* 51(5), 4282-4286 (1995)
- D. Helbing, L. Buzna, A. Johansson and T. Werner, *Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions*, *Transportation Science* 39(1), 1-24 (2005)

C. Burstedde, K. Klauck, A. Schadschneider and J. Zittartz, Simulation of pedestrian dynamics using a two-dimensional cellular automaton, Physica A 295, 507-525 (2001)

H. J. Huang, R. Y. Guo, Static floor field and exit choice for pedestrian evacuation in rooms with internal obstacles and multiple exits, Physical Review E 78, 021131 (2008)

Observations from student exercises and proposed experimental scenarios for human behavior data collection

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Experiments and field observations have been a primary source for data used to develop empirical models and inputs for computer software for evacuation simulation (Fahy, 2002). Although researchers have been highlighting the need to gather additional data from various building and occupancy types, across a broader spectrum of occupant demographics, data remain scarce (Proulx G. , 2008). There have been some attempts to develop a general framework for data collection, especially during fire drills (Gwynne S. M., 2010; Proulx G. , 1996). However, specifics about the architectural settings and occupancy type are often not addressed. This is unfortunate, as these are important factors that can assist in identifying certain behaviors which can be implemented in various computer evacuation models, such as influences on exit selection, occupancy-related individual and group behavior, and potentially issues associated with different cultural norms.

As a means to help students learn more about the importance of various human and building factors on occupant use of egress systems, and to help generate additional data for analysis and use in evacuation modeling, students in the Worcester Polytechnic Institute course, FPE 580M, People and Fires, were asked to undertake an experiment-based project related to human behavior and pedestrian movement. In this experiment-based project, students were asked to identify a human behavior or movement attribute of interest, observe people in public spaces under normal conditions, collect and analyze the data, and present their findings. To help guide the students, four potential scenarios with minimum requirements for the space and number of occupants were suggested (These scenarios were not required to be used since the course included on-campus and distance learning students, and flexibility was needed to accommodate data collection in off campus environments). In the end, data were collected over a range of different types of environments such as university class rooms, auditoriums and transportation terminals. While the outcomes of these exercises do not necessarily constitute complete or repeatable data sets, some insights were developed, which may help inform future experimental plans and data collection exercises. This paper discusses the suggested experimental setups, some of the student project findings, some of the challenges faced during data collection and analysis, and suggestions for others embarking on similar exercises in the future. Some observations of potential interest include the following.

Impact of counter-flow on movement speeds. Counter-flow is a concern when any type of simultaneous bi-directional flow may occur within the same components of the means of egress system. In two separate studies, students assessed the effects of counter flow within a corridor on occupants' walking speed. In both studies, occupant movement speed was 10% to 50 % lower than the data reported in the SFPE Handbook, even at low occupant densities. Occupant age, building architecture, and use of the buildings all likely played a role.

Exit selection. Occupants tend to choose to evacuate a space through a familiar route during an emergency since that it is easier than the process of finding another route and involves less effort (Keating, 1985; Passini, 1984). Though it is suggested that occupant redirecting to another exit depends on length of the queue and distance to the exit (Gwynne, Galea, Owen, Lawrence, & Filippidis, 1998-99), some of the students' observations showed otherwise. In two studies covering different university lecture halls, the students observed that the majority of the occupants chose to evacuate through the familiar exit, and did not change their exit choice even when there were queues. In addition, the egress route taken appeared to be more closely aligned to their 'exit of choice,' rather than shortest travel distance to an exit, which is contradictory to many algorithms used in egress models.

Movement speed on stairs and escalators. Stairs remain the primary means of egress from multi-story buildings. However, much of the available data is outdated and may not be applicable nowadays due to changes in demographics (Proulx G. , 2008). This also applies to escalators, which are usually not considered as official parts of egress systems during emergencies. In studies covering occupant movement and behavior on stairs and escalators, students observed movement speeds under a variety of conditions, such as carrying large objects, walking in groups, and using mobile devices. Outcomes suggest that current data may not reflect actual speeds, and illustrates areas where additional research could be beneficial.

Data collection for occupant egress behaviors can provide much needed data to the engineering and research communities. While for some the ideal setting for data collection would be through actual fire incidents, it is suggested that observational data for behavior and movement during normal conditions can still yield valid insights, not only for additional research, but as input for model validation and engineering assessment. To facilitate the collection of common types of data, which can be readily compared, assessed for goodness, and used in research and engineering analysis, it would be helpful to identify a collection of common experimental / observational setups for use by the research and academic communities. It is further suggested that the common experimental setups could be employed at a variety of universities, providing the potential for comparative data analysis across different societies and cultures. While the outcomes of the above mentioned exercises do not necessarily constitute complete or repeatable data sets, some valuable insights were developed, and it is hoped that lessons learned and insights gained will help inform future experimental plans and data collection exercises.

REFERENCES

Fahy, R. F. (2002). *Available Data and input into Models. National Research Council Workshop to Identify Innovative Research Needs to Foster Improved Fire Safety in the United States, Session on Human Behavior. National Research Council.*

Gwynne, S. M. (2010). *Conventions in the Collection and Use of Human Performance Data. NIST GRC 10-928.*

Gwynne, S., Galea, E. R., Owen, M., Lawrence, P. J., & Filippidis, L. (1998-99). *Daptive Decision-Making in Response to Crowd Formation in buildingExodus. Journal of Applied Fire Science, 301-325.*

Keating, J. P. (1985). Human Response During Fire Situations: A Role for Social Engineering. Research and Design 85: Architectural Applications of Design and Technology Research (pp. 285-288). Los Angeles: American Institute of Architects.

Passini, R. (1984). Wayfinding in Architecture. New York: Van Nostrand Reinhold Company Inc.

Proulx, G. (1996). Methodology for Evacuation Drill Studies. Ottawa, Ontario: National Research Council Canada.

Proulx, G. (2008). Evacuation Time. In S. o. Engineers, The SFPE Handbook of Fire Protection Engineers (pp. 3-355 to 3-370). Bethesda, MD: National Fire Protection Association.

Simulation of pedestrian dynamics with density control on a regular grid

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Discrete modelling of pedestrian dynamics often defines the system geometry on a two-dimensional regular grid. In the simulation, we must consider that the individual pedestrians are associated with an exclusive personal space. In the traditional two-dimensional cellular automaton model (CA) and its various extensions (see [1], [4], [10], [5], [7], [6], [8] etc.) this personal space is described by the cell size of the underlying regular grid. Hence, the state change on the grid can be applied to describe the system dynamics. This leads inevitably to a fixed personal space of the pedestrians. However, empirical data (e.g. [9]) show that in low density range, the size of this personal space varies significantly. In high density range, the size is clearly restricted by the physical size of the pedestrians. The purpose of this paper is to present a new modelling technique of pedestrian dynamics with consideration of advanced step calculation and density control on a two-dimensional regular grid.

The main contribution of the paper will be explained in the following parts.

1. In [3] we proposed a new method for the step calculation on a regular grid for the generalized case of local velocity larger than one grid cell size in one dimension per simulation cycle (sometimes also called multicell-step), which is necessitated by the representation of heterogeneous pedestrians. The local step choice on the underlying grid is more than a simple position change from a start position to a destination calculated by a “hardware” method, e.g. of the shortest distance, without taking into consideration the actual system dynamics. Instead, we allow small deviations on route within a local step, but with the restriction that the mathematical expectation of the possible step choices should reflect the original position transition exactly.

2. We introduce a projection mechanism to compute the intermediate steps for the position transition with consideration of local (cell) position availabilities. In the simulation cycle, we further introduce a balancing mechanism to decide the execution sequence of the simulation participants. This improvement, along with the first, enables a drastic reduction of the possible “deadlock” among the participants and at the same time gives a very reasonable explanation for the step calculation.

3. In reality, however, pedestrians’ personal space sometimes appears to be “compressible” to a certain extent in a way similar to gas particles. To our knowledge, in the CA model and its extensions, due to the nature of homogeneous rectangles (or squares) on the two-dimensional regular grid, the pedestrians’ exclusive personal space is fixed in the system construction, e.g. as $0.4\text{m} \times 0.4\text{m}$ in [1]. We proposed in [2] a solution for a flexible personal space. We observe that this exclusive personal space varies roughly in the range of $0.3\text{m} \times 0.3\text{m}$ (which represents the “incompressible” physical size of a pedestrian) to $1\text{m} \times 1\text{m}$ (which corresponds to the normal, unstressed state of an average pedestrian)

in reality. Hence in the current paper, the grid cell of the regular grid is defined to be of size $0.3\text{m} \times 0.3\text{m}$, and the modifiable personal space for the pedestrian can be considered as a composition of exactly one grid cell to a neighbourhood of 3×3 grid cells on the regular grid. We consider two cases.

(a) Firstly, the space requirement of a single pedestrian varies empirically in correlation with local speed. That is, a higher overall speed in the system results in a lower density. This is sometimes referred to as fundamental diagram. The fundamental diagram enables us to estimate the empirical density via the local pedestrian velocity, which can be acquired from the last simulation cycle. According to this information, some of the eight grid cells (apart from the origin) in the corresponding 3×3 -neighbourhood are to be declared as “inaccessible” for the rest of the simulation participants. This inaccessibility will be described by a transition function.

(b) Secondly, the former case considers the situation that a pedestrian behaves on his or her own behalf. In an extension of this, we distinguish the notion of “inaccessibility” under various contexts: Independent pedestrians tend to show greater “repulsive” effect to each other, whereas pedestrians which belong to the same group in the simulation environment tend to be “friendly” to each other, hence, the inaccessibility function is of a lower value.

Overall, the inaccessibility at an arbitrary cell position is always dependent on the behavioural context in the system. The density control on a local level can be achieved in this way.

We present two experimental cases to demonstrate our model. In the first experiment we simulate the group behaviours of the pedestrians, i.e. how some of these tend to stay close to each other (but the distance among them may still vary over a small range in the local step calculation), distinguishing them from other “foreign” pedestrians which exist in the simulation environment at the same time. A second experiment considers the intersection of multiple pedestrians groups with a simplification that all the participants are given pre-configured moving directions. The objective of this experiment is to demonstrate the density evolution, especially in certain critical regions (e.g. the intersection point where bottleneck phenomenon is more likely to take place), in correlation with local speed.

REFERENCES

- [1] C. Burstedde, K. Klauck, A. Schadschneider, and J. Zittartz. *Simulation of pedestrian dynamics using a two-dimensional cellular automaton*. *Physica A*, 295:507–525, 2001.
- [2] M.-J. Chen, G. Bärwolff, and H. Schwandt. *Automaton model with variable cell size for the simulation of pedestrian flow, 2008*. An electronic version can be retrieved at: <http://page.math.tu-berlin.de/~chenmin/pub/cbs080331.pdf> (accessed November 10, 2011).
- [3] M.-J. Chen, G. Bärwolff, and H. Schwandt. *A study of step calculations in traffic cellular automaton models*. In *13th International IEEE Conference on Intelligent Transportation Systems*, pages 747–752, 2010. An electronic version can be retrieved at: <http://page.math.tu-berlin.de/~chenmin/pub/cbs100709.pdf> (accessed November 10, 2011).
- [4] A. Keßel, H. Klüpfel, J. Wahle, and M. Schreckenberg. *Microscopic simulation of pedestrian crowd motion*, pages 193–200.

- [5] A. Kirchner, K. Nishinari, and A. Schadschneider. Friction effects and clogging in a cellular automaton model for pedestrian dynamics. *Physical Review E*, 67(5):056122, 2003.
- [6] A. Kirchner, H. Klüpfel, K. Nishinari, A. Schadschneider, and M. Schreckenberg. Discretization effects and the influence of walking speed in cellular automata models for pedestrians dynamics. *Journal of Statistical Mechanics: Theory and Experiment*, 2004(10):P10011, 2004.
- [7] H. L. Klüpfel. A cellular automaton model for crowd movement and egress simulation. PhD thesis, Universität at Duisburg-Essen, 2003.
- [8] K. Nishinari, A. Kirchner, A. Namazi, and A. Schadschneider. Extended floor field CA model for evacuation dynamics. *IEICE Trans. Inf. and Syst.*, E87-D(3):726–732, 2004.
- [9] M. Plaue, M.-J. Chen, G. Bärwolff, and H. Schwandt. Trajectory extraction and density analysis of intersecting pedestrian flows from video recordings, 2011. *Proc. PIA 11, LNCS 6952*, 285–296, 2011.
- [10] A. Schadschneider. Cellular automaton approach to pedestrian dynamics-theory, pages 75–85.

The non-symmetrical choice behavior during evacuation experiments in building with multi-obstacle

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Since the fatalities accidents in building fires occur more frequently and the safety issues of the lager-scale crowds that gather in a place for entertainment, ceremonies or education becomes an important element, more and more attention has been paid to understand human behavior in emergency and occupant evacuation in buildings, furthermore, considerable evacuation models and software have been developed. These models are mainly used to reproduce occupant evacuation process and predict evacuation results (such as evacuation time and occupant flow rate) in specific conditions. However, the calibration and validation of the models need lots of convincing empirical data. Unfortunately, the reliable data and information with regard to pedestrian and evacuation dynamics is still scarce. Additionally, there are few models focusing on reproducing and exploring the specific human behavior during evacuation process, such as selection behavior.

In this paper, we will study carefully the human choice behavior including exit selection and aisle selection based on the controlled evacuation experiments. We have conducted a series evacuation experiments. There were 102 college students took part in the experiments as evacuees. The place carried out the experiments was a university building and the experimental area consisted of a classroom, a passage and two stairs. During the experiments, at each end of the passage, there was an alarm which can give audible information representing stair exit status (open or closed). What needs to be emphasized is that the information may be false alarm or not activated which we controlled intentionally as a variable to study the respond of people to audile information during evacuations. The experiment variables consisted of alarm status, status of the stair exit, and the type of occupant initial distribution. There were two types of occupant initial distribution. One is nonsymmetrical distribution, that is, there were more individuals in the back of the classroom than that in the front of the classroom. And the other is symmetrical distribution, namely, all the students distributed in the classroom nearly evenly. We positioned totally nine cameras to record the experiment process.

By controlling the experimental variables, we conducted totally eight experiments which were divided into two categories: without and with particular groups. For without particular groups situations, all individuals had the same instructions, at the beginning of the experiment, all students sat on their own position in the classroom, and started to evacuate as soon as possible when the audile start signal was given. For each evacuee, the evacuation fell into three successive phases. Firstly, he/she had to move out of the classroom, and then chose a movement direction in the passage, moved down to the end of the passage and then went downstairs to the destination which was under the next below floor. If someone moved to a closed stair exit, he/she had to move back and evacuated via the other stair exit to the destination. All participants wore red hat in order to indentify clearly. For with particular groups situations, we chose randomly several students as particular individuals, and they were told that they

had to meet together at the area near the classroom exit in the passage before they moved to stair exit; furthermore, they had to keep together during the whole evacuation process. The ordinary individuals were the same as those in the first category, who were just told to evacuate to destination as fast as possible. The ordinary individuals wore red hats, and the particular individuals had different color hats according to different group. In addition, in the second category of experiments, there was only one stair exit (stair B) available, and it was told to all before evacuation, so they need not to estimate which escape direction was available when they arrived at the passage. The students were very familiar with the building, and highly motivated. During the experiment process, they were asked moving as fast as possible. After each experiment, all students came back to the classroom, and there was five minutes to rest, so they did not represent fatigue during the experiments. If anyone felt tired, he/she can drop out before each experiment. At each experiment, each individual sit on different initial position.

Based on the controlled experiments, we find that it is non-symmetrical for pedestrians' exit selection and aisle selection in classroom. In the first category of experiments, even though there were more individuals situated in the back of the classroom, the choice percentage of classroom front exit A was larger than that of classroom back exit B. This deviation was more apparent for the second category of experiments. Differently, there were much more individuals chose the classroom exit B. A massive number of pedestrians chose the middle aisles which were between seats, however, only few people chose the aisles which were next to the wall. In addition, bifurcation point, where people located at the same row divided into opposite direction, was biased towards the classroom exits.

We found that pedestrian destinations, that is, the choice of stair exit had significantly effects on occupants' choice of classroom exit which was pedestrians' intermediate destination, but the initial occupant distribution had little influence; pedestrians located in middle area tended to choose the aisle which is near the exit at the cost of taking more lateral movement between seats.

To explore the mechanism of the non-symmetrical choice behavior, we will simulate the evacuation process based on our proposed cellular automata model [1-2] and a microscopic simulation tool called NOMAD [3] which was developed in the Transport & Planning department of the Delft University of Technology. In the study, we will reproduce the non-symmetrical choice behavior, and then we will compare the results between experiments and simulations by considering the factors we discussed above (initial occupant distribution, expected destination, psychology behavior) to find which factors is most important.

The results in this paper are expected to provide valuable advice for large-scale crowd management both in normal and emergency situations and the optimization design of infrastructure layout in multi-obstacles buildings (such as classroom, theatre, and stadium).

REFERENCES

[1] Yang, L.Z., et al., *Cellular automata pedestrian movement model considering human behavior*. *Chinese Science Bulletin*, 2003. 48(16): p. 1695-1699.

[2] Yang, L.Z., et al., *Simulation of the kin behavior in building occupant evacuation based on Cellular Automaton*. *Building and Environment*, 2005. 40(3): p. 411-415.

[3] <http://citg.tudelft.nl/index.php?id=18769andL=1>.

Agent-based modelling and evacuation simulation for disaster preparedness and management

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INTRODUCTION

As periodic wildfires in the southern California, USA, or the nuclear Fukushima Daiichi nuclear disaster have shown, man-made and natural disasters might make human areas or regions (temporarily) inhabitable or the safety of inhabitants might be threatened severely, and the evacuation of this area required.

One major decision in facing disasters is whether to evacuate or not. Criteria for making that decision on a civil defense level are: the time available for evacuation, the socio-economic situation, the warning systems available, the severity and time evolution of the threat, and so on, and so forth. One major question is whether the available safe evacuation time (ASET) is larger than the required safe evacuation time (RSET). Another one is the feasibility traffic patterns that will result from an evacuation warning.

In this context, the GRIPS-Project (GIS-Based-Risk-analysis-Information and Planning System) (http://www.geog.uni-heidelberg.de/forschung/gis_grips.html) aims at providing useful and objective information for the decision makers facing such questions. Therefore, the multi-agent transport simulation toolkit MATSim (<http://www.matsim.org/>) is used to simulate the evacuation regarding two use-cases. The simulation of the evacuation of the district Wilhelmsburg in Hamburg, Germany, in consideration of an upcoming flooding. The second use-case examines the simulation of the evacuation of an area considering an industrial accident in the city of Essen, Germany. In neither case, the disaster is modeled directly, but handled as an external parameter “threat” that affects a certain region. One of the main goals of the project is the development of a computer tool that can be used by disaster managers as a decision support system. For that matter, both uses-cases are specified in cooperation with local authorities. Generally spoken, two central aspects are of interest: on the one side the tool might be used shortly before a disaster occurred. Then, civil defense authorities have to decide whether a district should be evacuated or not. On the other side the tool might be used in pre-disaster planning, i.e. adapting the traffic and civil defense infrastructure (like shelters).

From the scientific perspective, there are two central issues: extending the existing agent based queue model for transport simulation by a real 2D simulation for simulating pedestrians on the small scale and the development of a generic data model which describes a wide variety of evacuation simulations.

AGENT-BASED-SIMULATION

Existing models are either focusing on the simulation of large areas but simplifying geometric details or they are focusing on small-scale scenarios with high geometric resolutions but are not capable to

simulate larger areas because of the computational complexity. In this project, we are focusing on a multimodal simulation, where each mode of transport can be simulated in a different physical model. For vehicular traffic it seems to be reasonable to use a simulation model with a coarse resolution as for example the well known queue model. However, for more complex situations the queue model is too coarse. This is usually the case when it comes to pedestrians who are navigating through complex environments like train stations, where hundreds or even thousands of pedestrians try to get on a city railway. This is a particular problem in Hamburg, since the city railway is part of the authorities evacuation plan.

When doing multimodal simulations there is also a need to have mode change options. For example a pedestrian might start at home and walk to the next bus stop. After she has reached the bus stop, she has to wait for the bus. When the bus arrives she has to get on the bus. Now let's assume the bus takes her to the next train station, where she leaves the bus and walks to the platform to get on a city railway. The city railway then finally takes her out of the evacuation area. When modeling mode changes the physical simulation models not only have to be synchronized but also the boundary conditions have to be model carefully. This is highly non-trivial when coupling models with different geometric complexity.

DEVELOPMENT OF A GENERIC DATA MODEL DESCRIBING EVACUATION SIMULATION

The development of the tool includes two basic use-cases, but in general the tool is supposed to satisfy a wide variety of possible cases. One goal is the development of a data model which is suitable for a variety of scenarios. For that matter, the scope of the data model needs to be defined. It needs to be defined which types of scenarios should be satisfied and which scenario are to be out of scope. One important aspect regarding the scope may be the scale. For that, the evacuation of a plane or a single building is considered to be out of scope because the tool addresses regional evacuation only. Another aspect is the underlying data model since the evacuation software GRIPS uses a topological network and does not directly work on raster data. Those aspects, as the semantic of data, data formats, consistency, quality etc. will be analyzed in detail in the full version of the paper.

Besides the scope, the necessary input is analyzed. For now, the minimum information for performing an evacuation simulation in GRIPS is the grounding infrastructure, the population characteristics and the evacuation area. Regarding those information, the data structure must be specified. For example, the grounding infrastructure might be seen as a road network represented as directed graph. In any case, the network must be suitable for routing. However, there is different additional information required of pedestrian routing, automobile routing or public transport routing. Generally spoken, different scenarios require different input information. The data model needs to define the input data which are mandatory and which data are optional. Further the model should define some important scenario types for example pedestrian evacuation. In the full version of the paper, there will be represented some basic aspects that are to be regarded developing a data model for evacuation simulation.

CONCLUSION

The development of the GIS-based Risk-analysis Information- and Planning System will derive new findings in the area of agent-based evacuation simulation. For that matter, the development of the data-model will lead to some conclusions on the important aspects integrating data into evacuation simulation. Further the work on multimodal simulation models will expand the field of application of evacuation simulations to a wide area of scenarios.

An information-based model of pre-evacuation behavior for agent based egress simulation

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Ideally, when a fire starts a fire alarm goes off; all occupants hear this alarm and use the nearest safe exit to leave the building. However, this is hardly the norm. In many cases, occupants are desensitized from hearing false alarms and often do not start to evacuate until they are completely sure that it is needed. On January 19, 2000, a fire in Boland Hall in Seton Hall University killed three students because they had ignored the fire alarms assuming they were false. This uncertainty about the authenticity of the first sign of danger isn't an isolated incident [1,2]. Hence, when studying the behavior of evacuees, it is necessary to study and understand their actions from the time at which the fire started right up until the point where the last person evacuated. Modeling and simulation is one approach for analyzing and understanding egress behavior.

Software that simulates crowd egress is necessarily very complex because crowd egress from a building is itself a very complex system with lots of interacting elements (people, fire, alarms, etc.) each of which can cause different complications in the system. One of the most popular methods for studying and modeling complex systems is through Agent Based Models (ABM). In ABM a set of heterogeneous, intelligent entities called agents are programmed with behavior approximating humans and placed in a partially observable environment. Asynchronous interactions between agents result in macro-level dynamics which can help observers learn more about the system. Some studies [3] have expressed their reservations about existing computational models of egress. This is because many models make assumptions about human behavior that stand against evidence obtained through extensive experiments in social sciences.

One such assumption is regarding pre-evacuation behavior. As in the Boland hall incident, people don't start evacuating the building as soon as they hear an alarm; each cue that he observes has a certain impact on the person depending on his identity, social role and the circumstances. The process of pre-evacuation behavior consists of two phases [4]. The first phase involves the agent perceiving an event to be out of the ordinary. The second phase has two parts: The first is the process of the agent identifying the situation as a fire and the second part is the process of quantifying the risk to self and others which in turn determines the plan of action. In [4] Kuligowski presents a list of various factors and how each of them affects a person. These factors are categorized into three: subjective pre-event factors, subjective event factors and cue-based factors. The effect of each factor i.e. whether it increases or decreases the likelihood of the person changing from one phase to the next is also clearly documented.

A human is always processing information. However, he can only process a limited amount of information; some of this pertains to collision avoidance, others are cues and yet others are simply observations about the environment. These cues are cognitively processed by the agent only if the

amount of information they convey is great enough to be noticed in the sea of information that the agent is exposed to. For example, someone who is reading is unlikely to notice smoke forming outside his window until it is strong enough (i.e. gives enough information) to be noticed.

In this paper, we present a behavioral model for ABM of crowd egress. This behavioral model builds on the ideas of pre-evacuation presented in [4] by modeling evacuees as serial information processors. The evacuees identify and process information in terms of event cues which exist throughout the environment. Cues that convey enough information influence the agent's event knowledge base which is made up of different buckets; each corresponding to a particular phase of evacuation. Each bucket has a predetermined agent-specific threshold. Each cue that is perceived by the agent is checked for significance and depending on its effect (as described in [4]) is then put into the appropriate bucket(s). Rather than the cue itself, the characteristics of the cue (frequency, ambiguity, its source, etc.) are important. Once a threshold for a particular phase of behavior is crossed, a trigger is sent to the planner to effect a strategy change.

Evacuees do not have an indefinite memory of cues that they perceive. During an evacuation, an evacuee on seeing smoke a second time might get more stressed either because he had forgotten about seeing smoke earlier or because the smoke reinforces his feeling of danger. At the same time, if he has just seen a lot of smoke, seeing a little more would have no impact. This idea is modeled by implementing a cue memory. A cue that is in the memory of the agent has no effect on the buckets. A cue resides in the memory of the agent for only a short period of time. However, if perceived enough times, the cue is written into the memory permanently. In the model we include communication of the evacuees whereby agents can exchange event knowledge in the form of cues and environment knowledge. Exchanged information has a "trust" value associated with it, depending on the source, which determines whether it is added to the receiver's memory or not.

The paper illustrates the important of pre-evacuation behavior and a communication system through experimentation. These experiments evaluate the impact that pre-evacuation behavior can have on the overall efficiency of egress strategy. We show that with pre-evacuation behavior, information exchange and communication plays a critical role in the overall process and illustrate that egress strategy may be better designed to facilitate information exchange as well as efficient movement of evacuees.

REFERENCES

- [1] Proulx, G. (1995). *Evacuation Time and Movement in Apartment Buildings*. *Fire Safety Journal*, 24, 229-246.
- [2] Purser, D. (2001). *Quantification of behavior for engineering design standards and escape time calculations*. *Safety Science*, 38(2), 157-182.
- [3] Santos, G.; Aguirre, B. E. (2004). *A Critical Review of Emergency Evacuation Simulation Models*.
- [4] Kuligowski, Erica D. (1999). *The Process of Human Behavior in Fires*. NIST Technical Note 1632.

Venue suitability for large-scale events from the standpoint of crowd safety

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Major crowd disasters that have occurred since the turn of the 21st century include: the accident at the “32nd Akashi Citizens’ Summer Festival” in Japan in July 2001, which caused 11 deaths and 248 injuries; the accident at the “Love Parade” in Duisburg, Germany in July 2010, which killed 21 people and injured over 500 people; and the accident at the Phnom Penh “Water Festival” in Cambodia where more than 500 people were killed and more than 600 people were injured. Analysis of these accidents revealed various factors: crowd accidents are very likely to be caused by an interrupted flow of high-density crowd, but setting of crowd traffic control lines during the security planning stage to prevent the interruption of high-density crowd flow would be unrealistic because the total length of such line would very long. In addition, even if the best possible safety measures are taken at the event site, the movement of the crowd could exceed the security capability, making it difficult to avert the occurrence of a crowd disaster. Based on this finding, we carried out analysis with focus on the “venue suitability” which should be determined during the event planning stage. The result of the analysis showed that the venue suitability from the viewpoint of crowd safety depends on the number of visitors, the type and content of the event according to the venue space utilization plan, and the crowd movement in the access routes to and from the venue.

HYPOTHESIS REGARDING VENUE SUITABILITY

The suitability of a venue for any given event is thought to depend on the number of visitors to the venue. The venue space utilization plan would determine crowd movement within the venue. The content of the event may affect the characteristics of the event and the types/ages of visitors. The type of the event may affect the crowd movement within the venue and required venue space capacity. The content of the event would determine the crowd movement to and from the venue and within the venue during the event. Unless these crowd movements are smooth, it is highly probable that there would be excessive accumulation of people.

CASE STUDY 1

A crowd disaster caused by the incorrectly predicted number of visitors and the crowd movement in an access route to the venue

1) Overview of the interrupted high-density crowd flow

The “Japan Countdown 2001” was held at Okura Beach, Akashi City, from the evening of December 31, 2000 to the dawn of January 1, 2001. During the dramatic light illumination show and firework display, an interrupted flow of high-density crowd occurred near the south-side end of the pedestrian overpass connecting the event venue to the nearest railway station. The estimated crowd density was 10 to 12 people per square meter, which was on the verge of a stampede. Urgent security measures were taken to

successfully avoid a stampede. Seven months later, however, a similar interrupted flow of high-density crowd occurred on the same pedestrian overpass, causing a fatal stampede, during the 32nd Akashi Citizens' Summer Festival held at the same venue.

2) Factors affecting the venue suitability

The number of visitors predicted by the event organizer was 25,000, but actual number of visitors was 55,000, 2.2 times more than the prediction. The method for prediction had a significant defect; the organizer did not take into account the nearby residents who would come to the venue.

As for the crowd control plan in the access routes to the venue, if the number of visitors was 25,000 as predicted by the event organizer, it would be possible to lead the returning crowd through the access routes in one and a half hours. If the number of visitors was 55,000, on the other hand, the returning crowd of approximately 44,000 people would come flooding on the pedestrian overpass, causing an interrupted flow of high-density crowd. To prevent this, it would be necessary to set a crowd traffic control line 3 m in width and 944 m in length. In addition, the time taken for the entire crowd to pass through the pedestrian overpass was estimated to be three hours in theory. Crowd control under such conditions was unrealistic considering that the event was held at midnight on a new year's day. Apparently the venue was not suitable for such an event.

CASE STUDY 2

A crowd disaster caused by the incorrectly predicted number of visitors, inadequate venue utilization plan, and crowd movement

1) Overview of the crowd disaster

At the 2010 Love Parade festival held in Duisburg, Germany, a crowd of people to the parade venue ran head-on into the on-coming crowd returning from the venue, causing an interrupted flow of extra high density crowd and occurrence of a complex critical crowd wave. Twenty-one people were killed and over 500 people were injured due to crowd pressure and fall.

2) Factors affecting the venue suitability

The number of visitors predicted by the event organizer was one million. The police asked the organizer to submit the document validating the prediction. The actual number of visitors was estimated to be 480,000 based on the past records. The event is a typical mixed-type exciting music festival attracting young people.

The festival features stage music by and floats with music moving in front of the audience. The event venue was sandwiched between an expressway on the east side and a railway on the west side. Since the north-side access route was limited for use by the interested party of the event, visitors could only use the south-side main access road and sub access road. The venue was therefore a bottle-shaped, confined area.

CONCLUSION

Prevention of a crowd disaster in the venue of a large-scale event begins with the checkup of venue suitability during the event planning stage. It is essential that the event organizer, event planner, security company employed by the organizer, police, fire agency, transportation company and all other concerned parties share information and make discussions from comprehensive point of view.

Poster exhibition

Unsorted list

Rainer Könnecke, IST GmbH, Frankfurt am Main GERMANY

Effect of social groups on crowd dynamics - empirical findings and numerical simulations

Michael Seitz, Technische Universität München, München GERMANY

Modelling pedestrian group behavior in a cellular automaton

Manuela Di Mauro, Earth Observatory of Singapore, Singapore SINGAPORE

Pedestrian-vehicles interaction during evacuation: agent-based hybrid evacuation modelling of Southeast Asian cities

Marijn Swenne, Leiden University, Leiden NETHERLANDS

Optimizing pedestrian environments with evolutionary strategies

Nese Cakici Alp, Gebze Yüksek Technology Institute, Gebze TURKEY

Occupants emergency behaviour in turkey

Hubert Klüpfel, TraffGo HT GmbH, Flensburg GERMANY

The Loveparade tragedy 2010 – causes and consequences

Amir S. Sahaleh, Swiss Federal Institute of Technology, Lausanne SWITZERLAND

Microscopic calibration and validation of pedestrian models: Integrating discrete choice model into social force model

Mohcine Chraibi, Forschungszentrum Jülich GmbH, Jülich GERMANY

OpenPedSim: A framework for pedestrian flow analysis

Dirk Durst, Feuerwehr Kerpen, Kerpen GERMANY

Large-scale multi-modal evacuation analysis with an application to Hamburg

Effect of social groups on crowd dynamics - empirical findings and numerical simulations

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Major large scale events like public viewing, open air concerts or large festivals make high demands on all responsible parties, especially with respect to human safety. From disasters that occurred in the past it can be concluded that crowd incidents with serious consequences to life and health of people can have a variety of causes. So it is not possible to focus on emergency situations alone, but it is required to analyse a large number of scenarios in the forefront of such large scale events. Usually, such scenarios will comprise high density crowd movement. The lack of information on limiting factors like number of visitors, available space and behavioural aspects makes it difficult to define and assess scenarios for reliable safety concepts. Hence a joint research project titled EVA (Risiko Großveranstaltungen – Planung, Bewertung, EVAkuierung und Rettungskonzepte) has been established in order to define and analyze relevant design parameters. The EVA project started in March 2009 and will be finish by February 2012. This paper will focus on empirical data collection and analysis and its use for the calibration and validation of the microscopic evacuation and pedestrian dynamics model ASERI. The facet of the total EVA project presented here was covered by two of the project members, the German Fire Protection Association (vfdb) and IST GmbH.

A large amount of data - mainly in the form of video recordings - was collected by Dirk Oberhagemann and his vfdb team. Further empirical input was provided by the Disaster Research Agency - Institute for Sociology of the Christian Albrechts University in Kiel and the Institute of Fire and Emergency Technologies (IFR Dortmund). While the data analysis from the vfdb group was essentially manually, the Fraunhofer-Institute for Chemical Technology ICT contributed computerized digitalization, filtering and visualization techniques.

International design parameters for assembly areas are strongly varying, including values as low as 0.7 persons/m² (Italy) up to 4 persons/m² (Switzerland). In Germany a number of 2 persons/m² is applied. In some countries, these design parameters are formally restricted to buildings. The vfdb team has measured static and dynamic densities of pedestrians at various events in Germany and has furthermore analysed available archive material, e.g. from public viewing areas during the FIFA World Team Cup 2006. It was thus possible to collect a large amount of data on peak and sustained densities especially in dynamic situations. This data was further analysed with respect to the formation and movement of social groups. Usually, the majority of visitors of large scale events are members of social groups of size varying between 2 and 6 persons. By identifying the movement of such groups from the video sequences typical movement and behavioural patterns could be derived depending on group size and social factors like gender or parent-child relations. This behaviour was classified according to a parameter describing the tendency to conserve the compactness of the group during movement, with smaller groups being more offensive than medium or large size groups and families being less offensive

than groups of friends or casual acquaintances. It was furthermore possible to establish fundamental diagrams of walking speed and flow versus density for various group sizes. The effect of barriers on group movement was also investigated, however without revealing distinct features. It was thus concluded that the impact of barriers is more closely related to specific environmental factors, while group movement in general is strongly determined by social relations.

Microscopic modelling is a very fundamental and thus powerful method to investigate crowd movement in complex surroundings. This approach is able to cover consistently low and high pedestrian density regimes and can be applied to very large buildings, facilities and open areas. Within the EVA research project the microscopic model ASERI developed by IST GmbH was extended to applications typical for large scale events in emergency and non-emergency situations by modifying and extending the basic movement and behavioural sub-models and performing the respective calibration and validation work. This includes crowd movement at very high occupant densities and large total population numbers, counter-flow, lane formation and the collective movement of social groups.

It is now possible to specify the number of groups of a given size as part of a scenario for an ASERI simulation - either for an emergency situation like evacuation caused by immediate danger or non-emergency situations like crowd movement at high population density. Based on the specified number and size of groups appropriate initial distributions of groups are generated and distributed within the respective starting areas. The group velocity is governed by the minimum unrestricted walking speed of the individual group members. In order to model the dynamics of group coherence in a crowded environment, social affiliation is an important factor. ASERI includes four types of interpersonal relations: mutual positive, mutual negative, asymmetric (e.g. parent-child combinations) and neutral (no specific social relation). These relations define the range of mutual interpersonal distances that are tolerated without violating the coherence of the group. If due to the movement of other people in a crowded situation the interpersonal distance exceeds the respective tolerable limit, the group members further ahead will slow down or even wait until group coherence is again established. Using the relative distribution of group size and solitary pedestrians from the observation of the vfdb team the fundamental diagram is calculated for densities between 0.4 persons/m² and 2.4 persons/m². The following interpersonal relations were assumed for the respective groups: 50 % of the relations to other group members are of the type „mutual positive“ and 50 % of the „neutral“ type. The minimum interpersonal distance to a group member is 1 m for type „mutual positive“ and 5 m for „neutral“. With this set of parameters the empirical fundamental diagrams could be reproduced with good agreement.

Future work will include aspects of lane formation very crowded situations. Recent observations have documented oscillating effects in lane formation and even mutual backward flow at very high occupant densities.

Modelling pedestrian group behavior in a cellular automaton

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The study of crowd movement is very important for planning mass events and evacuations. Although many potentially critical incidents are hardly predictable, others like clogging, can be anticipated. Studies have shown that pedestrians in social groups frequently contribute the biggest part to crowds (Aveni, 1977; Singh et al., 2009), and that the groups have a significant impact on the crowd movement (Moussaid et al., 2010, Köster et al., 2012). Furthermore social cooperative behaviour does not stop in emergency situations, but continues or even gets stronger (Drury et al., 2009). However, most of the currently successful simulation models that are able to capture important characteristics of crowd movement, like density-flow relations or the formation of lanes, rely on models from physics, such as Newtonian mechanics, electrodynamics or fluid dynamics. We argue that the modelling of individual pedestrians in the form of e.g. particles is not sufficient to capture crowd movement. In the course of our model development we found that there is a need for agent-based modelling or, at least as in our case, agent-type mechanisms to supplement the physically inspired model.

The model of individual behaviour we use for our simulation is a calibrated cellular automaton that is able to simulate scenarios with a high number of pedestrians at the same time (Köster et al., 2010). We present a basic model for the movement of social groups in crowds. The first goal is to maintain group coherence for groups of size two to four in a realistic way while the crowd moves to a given target (Köster et al., 2012). Other models have been able to achieve this (Singh et al., 2009; Moussaid et al., 2010) and we discuss similarities and why they do not fit our needs: In our model, we first introduce an attractive potential around the member of the group who is most advanced towards the target. Secondly we let members that are falling behind speed up and members that are getting ahead slow down. Furthermore we introduce the concept of a group leader as a point of orientation for the other group members. Singh et al. (2009) also use a leader, but in their model the leader is a fixed person, whereas in our model the leader role can be passed on. Moussaid et al. (2010) use the center of mass as attraction point for all members. By analyzing video footage they come to the conclusion that microscopic behaviour can be explained by the urge to communicate. Moussaid's mathematical formulation is targeted for implementation in a social force model. It uses acceleration and deceleration, whereas the cellular automaton directly computes the direction and speed at a given moment. Hence we model the communication phenomenon in a way suitable for the cellular automaton approach.

We calibrate the model according to a small evacuation experiment we conducted (Köster et al. 2012). Due to the direct attraction to the leader, pedestrians can get stuck when they are separated by an obstacle. Thus the separation of groups by an obstacle has to be detected and resolved. One way to do this, is to let the lost members track back in order to find the group again (Seitz et al., 2011). Another solution is to use graph-based routing.

At mass events groups of bigger size are to be expected. A common assumption, yet without empirical evidence, is that large groups separate into smaller subgroups of size two to four (Moussaïd et al., 2010). We additionally assume that large groups also stay together as a whole in a less strict formation. No communication between members of two different subgroups is assumed. Otherwise we use the same mechanism we used for small groups but with weaker influence on the movement. The model for the subgroups stays identical to the one for small groups. Simulation runs imply a strong impact on crowd movement in certain scenarios.

The discussed mechanisms can be divided in two categories of decision making. The first approach combines different influences, e.g. target attraction, repulsion from other pedestrians, attraction to the leader and chooses the best compromise, most likely by adding up the potentials. This works as long as the situation is somewhat smooth. But there are situations where there is no reasonable compromise and one or more influences have to be neglected completely, as it is the case when a group member has been lost. Then the pedestrian has to decide whether to continue walking towards the target or try to find the group. We realize this binary decision by introducing agent-type mechanisms into the model. We conclude that the ability to take decisions that cannot be expressed through a physically inspired superposition of forces is necessary when it comes to more complex social pedestrian behaviour.

REFERENCES

Aveni, A.F. (1977) *The Not-So-Lonely Crowd: Friendship Groups in Collective Behavior*, *Sociometry*, 40(1), 96-99.

Drury, J., Cocking, C., & Reicher, S. (2009) *Everyone for themselves? A comparative study of crowd solidarity among emergency survivors*, *British Journal of Social Psychology*, 48, 487-506.

Köster, G., Hartmann, D., & Klein, W. (2010) *Microscopic pedestrian simulations: From passenger exchange times to regional evacuation*, in *Proceedings of the International conference on operations research: mastering complexity*, Munich, Germany, 1-3 September 2010.

Köster, G., Seitz, M., Treml, F., Hartmann, D., & Klein, W. (2012) *On modeling the influence of group formations in a crowd*, *Journal of Contemporary Social Science*, accepted.

Moussaïd, M., Perozo, N., Garnier, S., Helbing, D., & Theraulaz, G. (2010) *The Walking Behaviour of Pedestrian Social Groups and Its Impact on Crowd Dynamics*, *PloS ONE*, 5(4).

Singh, H., Arter, R., Dodd, L., Langston, P., Lester, E., & Drury, J. (2009) *Modelling subgroup behaviour in crowd dynamics DEM simulation*, *Applied Mathematical Modelling*, 33, pp.4408-4423.

Seitz, M., Köster, G., & Hartmann, D. (2011) *On Modeling the Separation and Reunion of Social Groups*, in *Proceedings of the International Conference on Emergency Evacuation of People from Buildings*, Warsaw, Poland, 31. March - 1. April 2011.

Pedestrian-vehicles interaction during evacuation: agent-based hybrid evacuation modelling of Southeast Asian cities

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In modelling mass evacuation, vehicles and pedestrian are usually modelled separately: allowing for some transversal interactions, to simulate pedestrian crossing the roads; and/or longitudinal interactions, by introducing some degree of reduction in the road capacity when pedestrian temporarily hop off and on the footpath (e.g. Meschini and Gentile, 2011; Wu and Wu, 2010). Such models assume that pedestrians will mainly remain within the delimited footpath during an evacuation. However, in many cities, particularly in Southeast Asia, pedestrian and vehicular traffic flows are not rigidly separated, even in normal (non-emergency) situations, see for example Chandra and Kumar (2003). In many cases, urban roads do not have footpaths, and both vehicles and pedestrians tend to occupy any possible free space in the roads. This coupling of pedestrian and traffic dynamics will greatly impact any large scale evacuation in such cities. To model this form of evacuation it is therefore necessary to accurately capture the impact which traffic has on pedestrians and vice versa.

This paper presents the results of a study aiming to develop a hybrid evacuation model able to target these issues, in order to better simulate hybrid pedestrian and vehicular evacuation in Southeast Asia cities. The paper presents a novel model that is able to simulate the interaction between vehicle and pedestrians, also capturing the peculiar conditions of the traffic in many Southeast Asian cities. In fact, most of the commonly used models for traffic (both macro and micro scale) are designed for specific orderly traffic, assuming that the vehicle would follow queuing patterns or lane divisions, features not applicable to many cities in Southeast Asia, which also present a very specific traffic composition, including a high rate of motorbikes and smaller vehicles. The model is designed to be scalable and is able to handle a large number of evacuees.

The resulting model is an agent-based model that simulates pedestrian and vehicles, using the java-based modelling platform MASON. The vehicle's movement is modelled using locally sourced empirical fundamental diagrams to represent the flows at the road links and intersections. At each time step, the vehicles move along the road links with a speed that is function of the flow (assumed constant during the time step) and the capacity of the road. Similarly, empirical fundamental diagrams for the intersections are used to model the relationships between the capacity and actual inflow, which determine the effective inflow and waiting time at the intersections. The pedestrian movement is simulated using Weildmann's diagram for pedestrian along the links and testing different algorithms for modelling the delay at the intersections, including empirical diagrams for pedestrian networks (e.g. Hoogendoorn et al, 2011). The capacities of roads and intersections, for both vehicles and pedestrian, vary at each time step as functions of the total number of agents (pedestrians and vehicles) and the ratio pedestrian\vehicles.

The first pilot site for this model is the city of Padang, Indonesia, which was chosen for several reasons. First, the city is expected to be affected by an earthquake and subsequent tsunami in the next decades. Although evacuation studies have been carried on in the past, our consultations with local emergency planners showed the need for more detailed analysis and assistance in translating them into actual evacuation plans. Secondly, the city was recently subject to a major earthquake that triggered a mass evacuation, which showed the typical traffic characteristics observed for Southeast Asian cities described above. Another reason for choosing Padang as pilot site is the existence of two models looking at the city's evacuation that can be used for comparison: a queuing model developed by Lammel et al. (2010) and a GIS-based model developed by Post et al. (2010). The latter is a GIS-based tool that statically calculates possible evacuation times based on the physical distances to safe places, land uses and population characteristics. The first is a pedestrian model developed by adapting a MatSIM queuing vehicular model, using Weidmann's fundamental diagram and assigning a 'storage capacity' for simulating the delay at the nodes. This model is able to simulate a large number of pedestrians, and embeds algorithms that calculate optimal or pseudo-optimal solutions. This model, however, include only pedestrians' movement. Also, looking at the 'optimal' solutions does not account for more complex scenarios. In this sense, the model proposed in this paper is designed to embed different route choices, which will be eventually treated as probabilistic ensembles. This paper presents the preliminary results of the application of this model, by testing the sensitivity of the results to different fundamental diagrams and route choices, and comparing the results with the above models, and with other available non-hybrid pedestrian and vehicular models. This application was carried on thanks to the collaboration with the local emergency planners and NGOs. Once refined, the model will also be applied and further validated to other Southeast Asian cities.

REFERENCES

- Chandra, S. and Kumar, U., 2003. *Effect of Lane Width on Capacity under Mixed Traffic Conditions in India*. *Journal of Transportation Engineering*, 129, 2, 155-160
- Hoogendoorn, S.P., Campanella, M.C. and Daamen, W., 2011. *Fundamental Diagrams for Pedestrian Networks*. In Peacock, R.D. et al. (eds.), *Pedestrian and Evacuation Dynamics 2010*, Springer, 255-264
- Lammel, G. et al. 2010. *Emergency Preparedness in the Case of a Tsunami— Evacuation Analysis and Traffic Optimization for the Indonesian City of Padang*. In Wolfram, W.F. et al. (eds), *Pedestrian and Evacuation Dynamics 2008*, Springer, 171-182
- Meschini, L., Gentile, G., 2011. *Simulating car-pedestrian interactions during mass events with DTA models: the case of Vancouver Winter Olympic Games*. *Proc. of 90th annual meeting of the Transportation Research Board*, Washington D.C.
- Post, J. et al. 2009. *Assessment of human immediate response capability related to tsunami threats in Indonesia at a sub-national scale*. *Natural Hazards Earth System Science*, 9, 1075–1086
- Wu, H. and Wu, W., 2010. *Microscopic Dynamic Simulation Model for Pedestrian-Vehicle Mixed Traffic*. *Proc. of IEEE International Conference on E-Health Networking, Digital Ecosystems and Technologies*

Optimizing pedestrian environments with evolutionary strategies

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INTRODUCTION

Many pedestrian crowd simulators have attempted to emulate or study their behaviour for the purpose of predicting how pedestrians would behave in various environments. Amongst the most popular of these settings are the evacuation scenarios where all pedestrians have to exit a building as soon as possible. Optimizing this environment has traditionally been the work of architects or other professionals. We propose a method for optimising this geometric environment by use of an evolutionary strategy. Simulator predictions will determine the desirability or fitness of these environments. The simulator we build for calculating the fitness is based on Helbing's social forces model and point of visibility pathfinding. We will show that this approach generates surprising results and can generate geometries which help decreasing evacuation time.

PEDESTRIAN PATH PLANING

In order for the agent to reach his goal, he will avoid all obstacles in a most human like fashion (as apposed to the most efficient way). These obstacles can be classified as stationary or static obstacles and dynamic obstacles. The geometric environment is considered to be a set of static obstacles which will be circumnavigated mainly with use of a visibility graph. Fellow agents will be considered as dynamic obstacles circumnavigated by using the social forces model [1].

Between static obstacles, which are represented as polygons, a visibility graph is constructed representing possible global paths that agents can follow. Agents choose the path with the shortest estimated travel time, which in turn is based on length and congestion rates. From this path an attractor point needs to be selected for each agent to calculate the direction of its next step. Common techniques [2,3] don't work well for multi-agent scenarios in narrow environments. We designed a method that creates a polygon around an agent with the attractor point being the intersection of the polygon edges with the path or the last point on the path if no intersection is present. The polygon is constructed by creating perpendicular lines for each obstacle on it's closest point in relation to the agent. Then creating line segments by calculating the intersections of these lines and concatenating the inner line segments to construct a convex polygon.

To process dynamic obstacles, the social forces model would normally take all fellow agents into account and have them project vectors on the agent representing a social forces, pushing the agent away from the dynamic obstacle. The magnitude is related to the distance between the agent and obstacle. This creates some but not all of the emergent behaviour seen in pedestrians [4]. We added a second set of criteria based on Goffman's research [5] on how pedestrians take notice of other pedestrians. Both additions give us a model that is more true to nature and shows better path finding and better lane

formation in dense streams.

GEOMETRIC ENVIRONMENT OPTIMIZATION

With our geometric environment being a collection of polygons, we want to add or rearrange these in order to maximise the capacity or throughput. To automate this optimization process, we will make use of a heuristic optimization technique known as an Evolutionary Strategy or ES [6].

A heuristic approach was chosen because it is able to produce a good solution in a practical amount of time. The ES in particular was chosen because it operates in real-valued search space and suits the geometric environment which is in a continuous search space. Given a fitness function and a set of real-values, an ES will try to find a set of values that produces the best fitness with time increasing the odds of finding a better solution. In this particular case, the real valued numbers represent static obstacles. We use a translation where some numbers are used to represent the shape and some to represent the location of the obstacle.

EXPERIMENTAL SETUP

We constructed a scenario consisting of two parallel walls, making a corridor and dictating the general flow of the agents. Pillars are added between these walls of which the size and location are represented as real valued numbers to be optimised by the ES. Agents enter the scenario on opposite sides of the corridor and have their goal set to the opposite ends of their starting location. Throughput is measured by making a summation of all steps needed for each agent to reach its goal, where fewer steps equals a better fitness. As a control experiment we created the same corridor without pillars and used the simulator to calculate its throughput.

RESULTS

Results show that when placing pillars in a corridor, certain arrangements exist whose throughput does not vary significantly from having no pillars. Some of these local optima have pillars placed in the middle of the corridor. These pillars seem to split agents into streams and making them avoid future collisions. Currently we are testing additional scenarios with the goal of increasing throughput by either inserting obstacles (fences/pillars) or by rearranging existing obstacles (seating/small shops). Preliminary results look promising and will be available for the full paper.

OUTLOOK

Future research will consist of extending the agents with a psychological model based on the OCEAN model and introducing body factors such as weight, compressibility and injury.

REFERENCES

- [1] Proulx, G. (1995). *Evacuation Time and Movement in Apartment Buildings*. *Fire Safety Journal*, 24, 229-246.
- [2] Purser, D. (2001). *Quantification of behavior for engineering design standards and escape time calculations*. *Safety Science*, 38(2), 157-182.
- [3] Santos, G.; Aguirre, B. E. (2004). *A Critical Review of Emergency Evacuation Simulation Models*.
- [4] Kuligowski, Erica D. (1999). *The Process of Human Behavior in Fires*. NIST Technical Note 1632.

Occupants emergency behaviour in turkey

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During emergency in high populated buildings, like high-rise, stadium, theater and hospitals human life safety is very important. This populated buildings occupants must be protected by buildings design tactics. For a more effective circulation system design in the building, environmental factors and occupant characteristics should be examined thoroughly. For that reason since 1970's the aim of the scientific fire engineering and most of other disciplines like architecture researches for to understand human evacuation behaviour under emergency situation in buildings. Also every society has its own characteristics. Human populations have so many differences in respect of physiologic, anatomic, behavioural and anthropometric views. Those differences occur for the reason of the interaction of genetic nature, environmental factors and cultural living standards of the society. Due to this point, using Turkish human anthropometric, behavioral data is efficient to realistic output of evacuation analysis in Turkey. For this purpose a survey asked to occupants of two different buildings Survey answers analyzed with SPSS statistical software. Dispersions given by software which are determining the emergency behaviour of occupants compared the dispersions of U.S.A. and England occupants' characteristic's to understand cultural behavioural differences of societies. However more buildings and their occupants needed to analyzed.

Surveys were conducted in two different building for understanding occupant's emergency behaviour and psychology. Surveys of the different studies on the behavior of an emergency situation (Wood, 1972, Fahy and Proulx 1995; Sekizawa et al., 1999, Proulx and Reid, 2006) examined and evaluated prior to study survey was development. The main purpose of analyzing these surveys is to investigate occupant's emergency behaviour and to understand the dispersion of emergency behaviour changes in different occupants group.

The first of these surveys was administered on 01.04.2010 following the fire that broke out on the ground floor of the Faculty of Architecture of the GIT (Gebze Institute of Technology), the architectural plan of which is shown in Figure 1.a, on occupants who were in the building at the time of the fire. A total of 27 people work at the faculty of architecture, which consists of a ground floor and a first floor; in addition, graduate courses are given in the building at some hours of the week. At the time of the fire, there were a total of 17 people in the building. The survey questions were posed to these 17 people who were in the building during the fire. The second survey was administered on the employees of the Kocaeli Metropolitan Municipality (KMM) Building, the ground floor plan of which is shown in Figure 1. b. The building where 600 are employed consists of 2 towers, one with 5 and the other with 6 floors, merged with a 2-storey main building; the questionnaire was administered on 123 people from among the occupants of the ground floor, the 1st floor and the 2nd floor.

The purpose of the survey was to statistically identify the emergency behaviour and psychology of the occupants and the statistical breakdown of the 'during fire' behaviour as per the occupants' genders, their knowledge about the building, and their position in the building. The variables used in the analysis of the survey are given in Table 1. As independent variables are not metric, the Kruskal-Wallis test was employed, which conducts a one-way variance analysis between groups.

Table of dependent and independent variables:

Dependent variables	Independent variables
<ul style="list-style-type: none">• Occupant's age• Occupant's sex• Occupant's working floor• Occupant's duration time• Cue for fire perception• First reaction after fire perception.• Evacuation speed• Reaction after facing to smoke• First exit route choice in fire	<ul style="list-style-type: none">• Response to fire alarm

From the survey, it is understood that occupants demonstrate a tendency to use the emergency exit doors, yet fail to adequately picture the building in their minds. Among ground floor occupants, the ratio of those using the emergency exit doors and those using the windows are equal. Unlike the occupants of upper floors, it is statistically proven that ground floor occupants are more likely to use the windows for exit purposes. For Turkish people, it is seen that the emergency behaviour is not related to occupant age, but related to gender and the floor where the occupant is located. The floor where the occupant is located affects the occupant's escape performance. It is understood that the escape tendency of upper floor occupants is lower compared to lower floor occupants. When compared to other countries, the emergency behaviour of Turkish people appears to differ in terms of priorities and breakdowns. In the surveys, the emergency profiles of the occupants were drawn through analysis of a limited sample. Expanding these emergency profiles countrywide would increase the consistency of the profiles. Occupant behaviour trends and distributions also vary constantly and in the course of time with the developments and changes in building structures and in lifestyles. Hence, it would be appropriate to conduct similar surveys across the country and on a permanent basis.

REFERENCES

Bryan J., 1995: Behavioural Response to Fire and Smoke, the SFPE, Handbook of Fire Protection Engineering 2nd Edition, National Fire Protection Association, Quincy, MA, 3, 241-262.

Çakıcı N., 2011: Simulation And Representation Of Human Emergency Behaviour And Movement In Buildings Using An Agent Based Model, PhD Thesis, Istanbul Technical University, Istanbul, Turkey.

Fahy, R.F., Proulx G., 1995: A Study of Human Behaviour during the World Trade Center Evacuation, NFA Journal, 59-67.

Proulx G., Reid I. M. A., 2006: Occupant Behaviour and Evacuation during the Chicago Cook County Administration Building Fire, Journal of Fire Protection Engineering, 16, 283-309.

Sekizawa A., Ebihara M., Nakote H., Kubota K., Nakano M., Ohmiya Y. and Kaneko H., 1999: Occupant's Behaviour in Response to the High-rise Apartments Fire in Hiroshima City, Fire and Materials, 23, 297-303.

Wood G. P., 1972: The Behavior of People in Fires, Fire research note 953, Building Research Establishment, United Kingdom.

The Loveparade tragedy 2010 – causes and consequences

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INTRODUCTION

The Loveparade was an annual festival started in Berlin in the 1990s. It moved to the Ruhr Area in 2008 Dortmund, 2009 Essen, 2009 Bochum – cancelled, 2010 Duisburg.

The cities of Dortmund and Essen have around 600,000 inhabitants, Duisburg 500,000, Bochum around 350,000. In 2009 the event was cancelled in Bochum, mainly due to safety considerations. The official statement was that there was not enough room in the city to host such a large number of visitors.

SOCIAL AND POLITICAL CONTEXT

The Loveparade changed from Berlin to the Ruhr Area in 2008. In the year before, no Loveparade was held in Berlin. The reason was that the status of „political demonstration“ was no longer granted and therefore, the festival management had to pay for waste removal, traffic management, etc.

Lopavent organized kind of a competition between different cities in the Ruhr area for being host of the event. Its a bit comparable to what happens for large sports events like olympic games or football world championships (on a smaller scale, of course). At the same time, the Ruhr Area, which was – and still is – the heart of the German steel and coal industries, severely suffers from the structural changes connected to the decline of those industries.

THE DISCUSSION IN DUISBURG BEFORE THE LOVEPARADE

The discussion in Duisburg mainly focussed on financial aspects. Since there is no approved budget for the city, expenses can only be made if the regional government (Bezirksregierung) approves. Since the festival was cancelled in the year before, there was some pressure to find a solution for the financial „problem“, i.e.~finding sponsors to cover the costs for the city.

THE VENUE

The venue was a former freight rail station. It is very close to Duisburg central station. The overall size of the area is about 500,000 sqm. Only part of it was used for the Loveparade, though. Since it has In the north of the venue is the central station, east is the rail line (10 tracks) in the south there is an on-/off-ramp to the highway A59 which is the west border of the venue. There is an old building in the center of the area which was partially used during the day for screenings but not accessible to visitors. The highway A59 was closed during the day and marked as evacuation route and access path for first responders.

THE DAY OF THE LOVEPARADE

The day the loveparade took place was Saturday, July 24th. It was warm and sunny summer day. There was a delay when opening the venue for the public. The opening was scheduled for 10hrs, the delay was about 2hrs. The reason was that there was still work to be done to prepare the venue.

Most of the visitors came via Duisburg central station, which is a hub for ICE, IC, and regional trains as well as metro and busses. They were guided on to different paths to a tunnel and further to an on-ramp to the venue located in the south of the area. The first major event was scheduled at 17hrs. At 16hrs, several problems concerning the inflow to the festival area culminated in a stand-still at the upper end of the on-ramp.

A second ramp to the location around 40m west of the major ramp was not used on the day until the early afternoon when the stand-still occurred.

The density on the ramp increased further, when the stand-still on the upper end of the ramp could not be resolved and there was a police line on the ramp trying to mitigate the situation. Two more police lines at the entrances to the tunnel broke down which caused further pressure. The persons on the ramp saw three ways to escape the situation: The container of the crowd manager at the southern end of the ramp, a lightpost on the eastern side-wall and – most of all – a small stair at the western wall of the on-ramp. It was this stair where people suffocated and died.

The details of the crowd crush have been covered extensively. At this point, a hint to some sources should suffice (will be put into the full paper).

THE MEDIA COVERAGE

The media coverage was extensive. The disaster was mostly called „mass panic“. For clarification, we refer to the contribution „Large Scale Events Crowd Safety“ (Klöpffel, in these proceedings). It is important to stress the following point, though: The „panic“ is not the reason for the injuries and deaths. People do not die, because the panic. They panic, because they die. The reason for the panic is the extremely high density and forces and the imminent danger.

THE LEGAL CONSEQUENCES

There is currently (as of November 2011) a legal investigation going on. It has not yet been finalized. A preliminary report has been submitted to the state parliament of North-Rhine Westphalia.

LESSONS TO BE LEARNED

Different levels of analysis and detail are necessary when trying to understand how and why the disaster at the Loveparade 2010 happened. There have been mistakes in the planning, the design, and during the day. The aim of this paper was not to identify who did what wrong but to summarize the publicly available information and provide references for the reader. She can then draw her own conclusions. One lesson to be learned might be to have a focus on „soft factors“ like political pressures, group think, selective perception and reasoning. Another one might be the focus on the systems approach and the identification of positive feedback loops (like density → stress → noise → forces → density) which might be generated during an event like the loveparade.

Microscopic calibration and validation of pedestrian models: Integrating discrete choice model into social force model

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In recent years, pedestrian flow modeling, simulation, and optimization has received a surge in attention from the transportation research community. The focus of this attention is mainly on a) solving the tangible day-to-day problems of crowded public spaces, including, transportation hubs, shopping malls, etc. and b) optimizing the evacuation procedures from high occupancy buildings and centers in case of an unpredicted event. The prior could be of high interest for architects for design purposes to see how pedestrians move in buildings and also for transport engineers tackling with safety and transportation facilities integration problems in big hubs. The later would be of obvious use for securities and event planners organizing big sport matches, festivals, concerts, etc.

In comparison to vehicle flow simulation, pedestrian movements are more heterogeneous. Pedestrians can walk in any direction and can change their trajectory towards almost anywhere that they decide to. Unlike vehicles that are machines with known and predictable capabilities and way of moving, pedestrians' motion depends on their way of thinking, and interacting with others. These are among the reasons for which pedestrian modeling is considered to be more complicated and subtler than traffic flow.

Models are considered as simplified representation of the reality. In fact, the goal is to find models which are as simplest as possible, but at the same time could reflect realistic behaviors. Generally, pedestrian modeling is done in two different scales i.e. macroscopic and microscopic. In microscopic models each pedestrian is represented separately as an individual agent and his/her behaviors are explored independently. While in macroscopic models pedestrians are analyzed in groups and crowds where the state of the system is generally described by mass densities, flow and average velocity (Schadschneider, Klingsch, Klüpfel, Kretz, Rogsch, and Seyfried, 2008). Several modeling approaches in both scales have been already put forward into the literature. For instance, we can mention fluid-dynamic and gas kinetic models that are macroscopic models where pedestrians dynamics took inspiration from hydrodynamics or gas-kinetic theory. In recent years more attention has been focused on microscopic modeling, where Cellular Automata and Social force models can be cited.

Social force model describes pedestrian behavior through so-called social forces where interaction with environment and other people is explained by attractive and repulsive forces. This model uses Newton's equation to calculate the forces. Basically the approach looks like:

$$dv /dt = F(t) + \text{fluctuations}$$

Where the fluctuation term takes into account random variations of behavior and $F(t)$ gathers social forces necessary to describe human interactions. The latter is constituted of three forces. These forces represent the acceleration term depicting the desire to achieve a certain velocity by the pedestrian, the repulsive effect evoked by other pedestrians, borders and walls and, the attractive force (Helbing and Molnar, 1995).

Social force model is the most operational pedestrian model that currently exists, meaning that it is used by the most well-known simulators and in the majority of pedestrian projects and studies. On the contrary this model has never been microscopically (behaviorally) validated. In general, validation of microscopic pedestrian models is performed by comparing aggregate (macroscopic) model parameters (flows, speeds, densities, etc.) or emerging patterns (dynamic lane formation, formation of diagonal strips in crossing flows) with empirical data. The social force model has been validated in the same macroscopic way for self organization phenomena i.e. bottleneck oscillations, lane and strip formation.

In doing so, it has been shown that the model is able to predict macroscopic flow conditions with reasonable accuracy. But it is unclear if it only provides reasonable „average“ macroscopic predictions or it is able to describe individual walking behavior accurately as well (P.Hoogendoorn and Daamen, 2007). In social force model, forces are firstly defined by physical concepts (Newton's equation) and then have been applied to pedestrian behaviors. In a more microscopic and behavioral approach we stick to the common hypothesis that individuals make different decisions, following a hierarchical scheme: strategical, tactical and operational. Destinations and activities are chosen at strategical level, route choices are performed at the tactical level and instantaneous decisions while walking and interacting with others are taken at the operational level. Our focus is on pedestrian walking behavior, naturally identified by the operational level. Discrete choice models go deeper in behavioral aspects of pedestrians reactions rather than physical ones. Taking into account different characteristics of people and choices, these models deal with pedestrians' behavior by exploring the way they choose their activity, their destination, their route etc. As an example, Robin (2011) proposes a walking pattern (next step model) where pedestrians choose their next step among 33 alternatives in a discrete choice framework. This model is microscopically validated with real data which proves that it can to a large extent reflect real pedestrians' walking behavior. On the contrary, discrete choice models are not as operational as the social force model.

Obviously, the idea that comes to mind is trying to integrate a discrete choice model into the social force model to take advantage of both models' strong points and to have an operational model which is also validated in terms of microscopic behavior. This paper presents an operational validated model by merging these physical and behavioral models. The model is developed and used in a commercial simulator (VISSIM) based on social force model. It is validated with two rich data sets. One is in SV building at EPFL (Ecole Polytechnique Federale de Lausanne) where at not a big entrance hall people's walking behaviors become extremely interesting at certain periods of the day since they take different entrances and exits depending on various destinations that they can reach by passing this hall. And the second data set stem from Lausanne train station which experiences interesting passenger behaviors as a highly frequented multi-modal transportation hub.

OpenPedSim: A framework for pedestrian flow analysis

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In recent years pedestrian dynamics has gained more importance and a lot of attention due to continuously growing urban population and cities combined with an increase of mass events. In this context simulations are already performed and critical decisions are taken based on the simulation results. For this purpose several software packages have been published. Most of these software are commercial, or do not give an insight in their functionality. While this might be of little importance for some end user, it is very important for researchers to know exactly what the models are performing. This constitutes a significant advantage in the interpretation of the results.

In this paper we introduce OpenPedSim (Open Pedestrian Simulation), an open source framework for performing pedestrian simulations. This framework should support researchers by the development of new models by providing a suitable environment with appropriate interfaces.

The motivation for starting OPS was the following:

In many universities and thesis projects, a lot of time is spent on setting up a proper environment for investigating new ideas. Although the main objective is, for instance the development of a new pedestrian model, the work on utilities like an editor for the geometry or for the input of data, a tool for visualizing the results is an enormous entry barrier. Another side issue is the definition of proper interfaces. Only after those steps have been successfully taken, the „real“ work starts. And usually this work has to be done as fast as possible. Most of the time, the result is a code which is neither reusable, nor maintainable, nor scalable.

We are hereby introducing OpenPedSim, an open source framework for performing pedestrian simulations, to address those issues. The primary goal of OpenPedSim is to provide students and researchers with a toolbox that will let them focus on their main task, i.e. the development, calibration, and validation of new models or model features. OPS is currently focusing on evacuation, but will be extended to cover other areas as well. These are: passengers exchange, commuter traffic in railway stations, etc. Finally, OPS also provides sample data sets for calibration and validation. We are developing some standards and benchmark scenarios for evaluation pedestrian simulations. This task is closely linked to Rimea and the IMO validation cases.

OpenPedSim is hosted at Sourceforge. The different modules of OpenPedSim can be downloaded from <http://sourceforge.net/projects/openpedsim/files/>. There are also pre-compiled binaries for the common platforms (Windows/Linux/OSX). The latest code can be downloaded via svn with the command at the url: `\url{https://openpedsim.svn.sourceforge.net/svnroot/openpedsim}`.

As said above, a major aim of OPS is to accelerate the work of students, researchers, and programmers, that are focusing on pedestrian dynamics. Therefore, OPS provides well-designed interfaces and file-formats to reflect the steps that have to be carried out when simulating pedestrian flows and analyzing the results.

Usually, a pedestrian flow simulation comprises the following steps:

1. Importing the geometry (either from CAD or from GIS)
2. Specifying the population (synthetic population, including activities)
3. Specifying further parameters (e.g., environment, hazards)
4. Performing simulation runs (including parameter variation, stochastic variance, etc.)
5. Data Analysis and Interpretation

The single modules of OPS are designed to provide the capabilities for performing each of these steps. At the same time, the steps are separated from each other („divide and conquer“). From a technical point of view, the modules are the focus. The following list shows their application domain:

1. Editor -> Geometry
2. Editor -> Population
3. Editor-> Environment
4. Simulation Kernel -> Performing simulation runs
5. Visualizer -> Visualization of the simulated agents off-line and/or on-line.
6. Reporting Tools -> Data Analysis

The OPS framework consists of loosely coupled modules. I.e., the modules can be used individually. The editor allows the creation of new scenarios for a simulation. A scenario comprises a geometry, information about the pedestrians and other constraints. Constraints can be the state of rooms or doors, blocked for instance. These are the input to the models. The results of the models are then visualized using the module designed for that purpose.

The results are the trajectories of the individual pedestrians in the simulation. But other models can output other type of results as well, density for instance. In addition, a measurement tool analyses the results. Finally a report is generated.

A very important point here is the specification of the different interfaces. A clear and open specification facilitates the integration of new components, in this case of new models. All interfaces are not specified yet.

OpenPedSim actually consists of the following modules:

1. OPSed: The editor provides geometries for continuous models as well as for cellular automata.
2. OPSgcfm: Is an implementation of the generalized centrifugal force model
3. OPSfast: Is an implementation of the F.A.S.T. cellular automaton model
4. OPSffca: Is an implementation of the Floor Field Cellular Automaton
4. OPSTraVisTo: The Visualization of the trajectories. It makes use of QT and the Visualization Tool Kit library (VTK) for rendering the scenes.
5. OPSreport: Reporting Tools contains modules specified in the OPS framework and integrated in the overall work flow. Due to limited resources, the implementation of OPSreport has not yet started.

At the moment the system is loosely coupled. A further integration of the different modules might be worthwhile. One idea is to provide a tool called OPScontrol. This tool then might run a certain number

of simulations based on a valid model created with OPSed. The next step would be to identify the simulation run which should be investigated further and run this simulation with a detailed output, i.e. the trajectories of all persons in detail. Finally OPScontrol would invoke OPSreport to create a PDF containing a summary of the simulation results. Of course, there are many more possibilities. Another idea is to use several simulation kernels for the same scenario and compare the results „automatically“ (i.e. by running OPScontrol with the appropriate (command-line) parameters).

Large-scale multi-modal evacuation analysis with an application to Hamburg

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Evacuation is one possible option when facing natural or man-made risks. The evacuation of a building block, part of a city, or even a whole city or region is a far-reaching measure, though. Therefore, it is usually also the last measure and only taken when a social catastrophe is impending.

The city of Hamburg was hit by flooding in 1961. The homes of 50,000 people were destroyed and a total of 315 persons died. The situation today is not comparable to the situation in the early 1960s. Back then, many buildings were still barracks and built or repaired just after world war II. These few considerations show the complex context, in which decisions about evacuations are made. In order to reduce the complexity for the decision makers simulations for the prediction of evacuation times and potential congestion or delays are one option. They can provide objective criteria and make the consequences of certain alternatives more intuitive by visualizing them based on well-known representations of the city like street maps.

In this paper we will present results on a microscopic evacuation simulation combined with different calculations for the evacuation time. Four different modes of transport are taken into account: walking, busses, railway, and cars. In detail: walking to shelters, walking to bus and train stations, bus shuttle and local trains, and finally motorized individual transport by car. The major result is a range for the evacuation time. It is in the order of three to four hours which fits into the overall time-frame of nine hours for the total time available (i.e., the available safe evacuation time ASET). ASET consists of three hours for preparation and warning, four hours for evacuation, and two hours as buffer. ASET must be larger than the required safe evacuation time (RSET), which is in our case determined by the simulations and calculations.

The Available Safe Egress Time (ASET) is limited first of all by the external risk. In our case, the external risk is flooding. To be more specific: we assumed a leakage of one of the dams. Hydrological and hydrodynamic simulations are routinely performed by the civil defense authorities in Hamburg. On that basis, a detailed plan exists, providing warning times and a time schedule for a large-scale evacuation. The overall schedule is 9 hours, for observation and warning there are 4 hours and 1 hour, respectively. Therefore, the current time frame for individual preparation and movement is four hours.

PRE-MOVEMENT OR PRE-EVACUATION TIME

When assessing evacuation processes, many different phases of information gathering, decision making, communication, and feedback collection have to be taken into account. These phases are to some extent overlapping. In general, the overall time can be divided into the following parts:

Evacuation Time = Detection + Decision + Alarm + Individual Preparation + Movement

One major uncertainty is the individual preparation time. It might be influenced by the warning mechanisms and messages. For a different case study, the Indonesian city of Padang, up to 50% of the population stated they would stay in place in case of a Tsunami warning (Taubenboeck2009).

WARNING MECHANISM

There is a plethora of warning mechanisms planned for this evacuation scenario, ranging from radio messages and SMS to canon-shots, sirens, individual phone calls, etc. Details are given in (HPA2011, in German) and BSI2011 (in German).

PLACES OF REFUGE

The safe places are within the evacuation area as well as outside. In Hamburg-Wilhelmsburg, places of refuge are either higher floors of private buildings or public buildings prepared as evacuation shelters. The places of such shelters are shown in the warning brochure distributed to all inhabitants (see figure). Further places of refuge are outside the evacuation area requiring transportation. Several modes of transport are employed: motorized individual, bus shuttle, and local trains (S-Bahn).

SIMULATION MODEL

This paper presents results on the simulation of the evacuation of Hamburg Wilhelmsburg. In the simulation, 25,000 agents were distributed in the area of the Elbe island, where Wilhelmsburg is located. The model used is MATSim (www.matsim.org). The simulation was part of a comprehensive assessment taking into account public transport (by local trains and busses), foot traffic to shelters, and motorized individual traffic on the one hand. On the other hand, capacities of shelters and infrastructure, first responders, and information dissemination were taken into account. The traffic simulation module was used to determine the overall evacuation time for motorized individual traffic. Since the movement to shelters and the transportation by public transport (local trains and busses) is independent thereof, the maximum of the times for the different evacuation modes can be considered the overall evacuation time.

FIRST RESULTS

In the scenario analyzed an advance warning of 3 hours was assumed. This time is also used for the preparation of the emergency and rescue service.

For motorized individual traffic the overall evacuation time is less than 90 minutes. However, the transportation by public transport takes about four hours, which uses up the available safe evacuation time given local authorities. The service times for the public transport evacuation was based on an evacuation exercise performed in Cologne. In order to improve the situations an increase of the available transport infrastructure (i.e. number of busses/ trains) or a more effective usage of the existing transport infrastructure is needed. This would mean to increase the number of persons per bus or train. It has to be noted that the number of persons per bus was less than 20% as under normal conditions. This is due to the extensive amount of luggage carried by the evacuees.

FURTHER STEPS

The results presented here are embedded into a larger context, which is the GRIPS research project. More details about GRIPS are given by Walencial et. al. (in these proceedings).

Poster exhibition

Unsorted list

Daichi Yanagisawa, College of Science, Ibaraki University, Ibaraki JAPAN
Starting-wave and optimal density in a queue

Xuan Xu, China Academy of Safety Science and Technology, Beijing CHINA
Optimal exit choice algorithm for pedestrian evacuation dynamics

Dongyoun Shin, Eidgenössische Technische Hochschule, Zürich SWITZERLAND
Activity classification and user interface design for a crowdsourcing urban simulation platform using mobile devices

Stefan Nowak, Universität zu Köln, Köln GERMANY
A cellular automaton model for lane formation in bidirectional pedestrian flow

Antonin Danalet, Swiss Federal Institute of Technology, Lausanne SWITZERLAND
Pedestrian map matching using WiFi traces

Hubert Klüpfel, TraffGo HT GmbH, Flensburg GERMANY
Specific requirements for the egress simulation of large scale outdoor events

Khalidur Rahman, Universiti Sains Malaysia, Georgetown MALAYSIA
Analysis of pedestrian walking speed in a developing country: A factorial design study

Starting-wave and optimal density in a queue

Daichi Yanagisawa, College of Science, Ibaraki University, Ibaraki JAPAN

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Various kinds of self-driven many-particles (SDP) systems, such as pedestrian dynamics, vehicular traffic and traffic phenomena in biology have attracted a great deal of attention in a wide range of fields during the last few decades. Most of these complex systems are interesting not only from the point of view of natural sciences for fundamental understanding of how nature works but also from the points of view of applied sciences and engineering for the potential practical use of the results of the investigations. Especially, the interdisciplinary investigations for the dynamics of jamming phenomena in SDP systems, so-called Jamology, have been progressed by developing sophisticated mathematical model considered as a system of interacting particles driven far-from equilibrium. These contributions to analyze the mechanism of jamming formation tell that one of the most important factors to cause the jamming phenomena is the sensitivity, which indicates the time delay of reaction of pedestrians or drivers to the stimulus. As an example, if the reactions of drivers are extremely sensitive, they can avoid the traffic jam by adjusting their behavior immediately to their front car's movement. The reaction time of pedestrians is similarly important toward smooth movement of crowd. Moreover, we would like to point out that the wave of successive reaction in a queue, so-called starting-wave, plays a significant role for the waiting time of queuing system of pedestrians and vehicles, since quick-start in walking accomplishes the more smooth movement of crowds. In this contribution, first of all we investigate the relation between the propagation speed of pedestrians' reaction and their density by using mathematical model based on the stochastic cellular automata. Then, the optimal density to minimize the travel time of last pedestrians in a queue to reach the head position of the initial queue is investigated under taking into account the propagation time of starting-wave. Finally we verify these results obtained from mathematical model by performing the experiments of pedestrians.

Our mathematical model is built on the stochastic cellular automata, which recently prevails to model the stochastic transport in complex systems. Let us imagine that the passage is partitioned into L identical cells that each cell can accommodate at most one particle (pedestrian) at a time. Note that, in the following, we refer to "particle" as a representation of a pedestrian in a model and "pedestrian" as a person itself. The length of each cell corresponds to 0.5 meters by considering the reasonable volume exclusion effect of pedestrians. Moreover, a total number of N indicates the particles which are placed at equal distance H cell. The update rules of our cellular automaton model are as follows: first of all, only the particle at front of a queue moves forward. Then the following particle only the second particle in the queue can move forward. After the second particle moves forward, the next particle can start to move in sequence. These rules of pedestrians' walking are applied in parallel to all particles. Note that, in our model, in order to investigate the propagation speed of successive reactions, all of the following particles can not move forward before the starting-wave reaches to them. Therefore, unlike the usual stochastic cellular automaton models such as ASEP, ZRP, in our model, only if the next cell is empty

and predecessor had already moved, following particles can move forward with probability $p(h)$ which depends on their headway distance h . This hopping probability of particles $p(h)$, which indicates the velocity of particles, is given in analogy with the idea of Optimal Velocity (OV) function, which is often introduced into the mathematical model for vehicular traffic as a desired velocity of drivers depending on headway distance. This function is motivated by the common expectation that drivers have their desired velocity to do the comfortable driving. We have measured the propagation speed of starting-wave which is derived from the length of initial queue divided by the elapsed time under each given initial density which is decided by the initial value of particles on the cells, that is, N/L . The results obtained from mathematical model show the power law in the relation between propagation speed of starting-wave and the initial density of pedestrians.

If there is an optimal density to minimize the delay to get out from a queue or crowd, the control of density is possible to reduce the waste of waiting time. Moreover, if pedestrians stand in a line with large headway (low density), the starting-wave propagates fast under the long queue. Whereas, if they stand in a line with small headway (high density), the starting-wave propagates slowly under the short queue. Which situation decreases the waste of waiting time? The optimal initial distribution for a queue is investigated here by considering the fundamental relation characterized by the power law. The results obtained from mean field theory based on the mathematical model show that the optimal density does exist at a density, which depends on their walking velocity.

We have found that these results, that is, fundamental relation characterized by the power law and the existence of optimal density, are verified by performing the experiments of pedestrians.

In this contribution, we have investigated the propagation speed of pedestrians' reaction in relaxation process of a queue so-called starting-wave. The faster the starting-wave propagates, the more smoothly the crowd moves. We have revealed the existence of optimal density, where the travel time of last pedestrians to reach the start line for the initial queue is minimized by both analytical calculations and experiments. This optimal density inevitably plays a significant role to design not only the initial queue of pedestrians but also the traffic problems.

Optimal exit choice algorithm for pedestrian evacuation dynamics

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In the microscopic evacuation model, the desired direction of the pedestrian is consistent with the minimum-distance direction. However, the minimum-distance route may not same as the minimum-time route. The evacuation time is made up with the movement time to the exit and waiting time at the exit. The movement time is determined by the exit location, while the waiting time is determined by pedestrian distribution and exit width. The microscopic model usually solves the exit choice based on the distance, and other constraints are rarely taken into account. However, in some cases, the shortest distance does not necessarily guarantee the minimum evacuation time. For example, when there is a high occupant density around the nearest exit, the pedestrian will spend a lot of waiting time if he chooses the nearest exit. Instead, if he changes his option to select a farther exit, he may leave more quickly if there is a low occupant density around the exit. Moreover, suppose there are two optional exits, one of which has a shorter distance and smaller width, the other has a longer distance and larger exit width. Choosing the nearer exit rather than the farther one may spend more time because the exit width is too small to let the crowd pass quickly. The key of solving this issue is to help the pedestrian know how long he will wait at the exit. The waiting time is related to the pedestrian distribution and exit width. Thus, the individual evacuation time is not only related to the distance but also the pedestrian distribution and exit width. When choosing the exit, not only the exit position (evacuation distance) should be considered in estimating the evacuation time, but also the pedestrian distribution and exit width.

In this paper, the optimal exit choice algorithm is presented based on the microscopic model. The algorithm aims at the shortest individual evacuation time which is calculated in iterative method. The factors such as pedestrian distribution, exit position and exit width are all involved in the time evaluation function in the algorithm. Taking a room with multiple exits as an example, the cellular automata model is applied to simulate the evacuation process, and the evacuation time with optimized and non-optimized exit choice are compared and analyzed.

To be noticed, for the reason that during the evacuation process, nervous and herding might influence the exit chosen behavior, the occupants might not change their decision as long as the exit they chose is available. As a consequence, in the present article we do not intend to introduce dynamical method to determine the exit option of the occupants. What is more, frequently changing signal of exit signs could induce potential crowd disaster when occupants follow these signals and change their moving directions from time to time. As a result, the optimal exit selection method is a statistic algorithm. The exit choice for each pedestrian is visually displayed by the exit selection zoning map. The zones occupied by pedestrians with different colors are associated with different exits. Each zone covered with the same color corresponds to one exit.

The results show that under the influence of the optimized exit choice, some people no longer choose the nearest exit but the exit with larger width or with lower occupant density around. The algorithm solves the problems of uneven and inadequate utilization of the exit in the evacuation.

As the exit choice changed, the evacuation time through each exit changed accordingly. The overall evacuation time, namely the maximum value, is the time when all the pedestrians leave the room. It is found that the overall evacuation time drops from the 850s to 564s for the optimized exit choice, which indicates that the evacuation efficiency increases by 33.64%.

The standard deviation of the evacuation time can reflect the uniformity of the exit utilization. The higher the value of the standard deviation is, the greater the difference of exit utilization is. The results show that the standard deviation of the evacuation time for the original exit choice is 195s, while the value for the optimized exit choice is 145s. It indicates that adopting the optimized exit choice realized the diversion of the crowd flow during the evacuation, and the waiting time was distributed approximately evenly.

Idle time of an exit is defined as the difference between the overall evacuation time and the evacuation time of the exit. It is found that compared to the original exit choice, the idle time for all exits with optimized exit choice decreases greatly. For the original choice, the average idle time is 520s and the maximum idle time is 781s. When taking optimized choice, the average idle time reduces to 226s and the maximum idle time 454s. The average idle time drops by 56.54%, which demonstrates that taking optimized exit choice effectively reduces the vacancy rate of the exit and enhances the utilization greatly.

The optimal algorithm gives the exit selection zone map which can provide reference for planning evacuation. As one evacuee cannot get global information of all evacuees in the room, they may choose the nearest exit but need to wait for a long time. Thus, it is necessary to guide evacuees to the most proper exits from the global perspective. The dividing line between different exit selection zones is the key to allocate evacuees. In case of emergency, the executor should assign some guiders near the dividing line to conduct evacuees to an optimal exit according to the zone map. In fact, the exit selection zone map from the results provides the placement of guiders and the guiding direction to the designer.

Activity classification and user interface design for a crowdsourcing urban simulation platform using mobile devices

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INTRODUCTION AND RESEARCH QUESTIONS

The research area of urban simulation methods has grown notably in recent decades. Most of the research topics that concern urban simulation have concentrated on defining the complexities of urban environments with certain rules and algorithms. However, cities are getting more complex and changes to them are being made at greater speed [2]. Therefore, current urban simulation modeling approaches based on rules and protocols are still struggling to reduce the gap between the virtual simulation environment and the real cities, since the behavior of citizens is frequently unpredictable and continuously adapting.

In this context, research is necessary to develop more fundamental simulation methods that can handle these complexities and changes, leading to new design decision support systems [3]. Therefore, this research was motivated with the following questions: What is the origin of the complexities and transformations of the urban environment? How can we approach the origin to deal with the urban complexities and transformations?

To answer these questions, we hypothesize that the diverse human behavior are the origin of the issues that result from all of the complexities and changes of the cities.

CROWDSOURCING URBAN SIMULATION PLATFORM AND KEYWORDS

In this paper, we introduce the idea of a crowdsourcing urban simulation platform using smartphones [1, 4]. Such development requires research to be conducted in numerous disciplines: social sensing, urban sustainability, mobile network, behavior pattern analysis, and social network services. It is based on the detection and classification of activity patterns (currently mainly focusing on traffic information), and on state-of-the-art interactive user interfaces in order to let user utilize the application easily. On the basis of these cutting-edge technologies, this research aims at the design and implementation of a practical participatory urban sustainability simulation platform.

OBJETIVES

As a result, we propose a participatory simulation environment that feeds sensed human behavior into an urban simulator, and thereby includes urban complexities and dynamics simultaneously. This research pursues to collect urban behavior data through the smartphone and suggests possible user benefits for their data sharing.

Therefore this research has following objectives:

- Establish sensing methods for mass data collection using smartphones

The first step of this research was to set up the basis for mobile crowdsourcing. This includes defining what kinds of data should be collected, how the data needs to be transformed to be useful for urban simulation, and how information can be fed back to the user.

- Classify the user's activity, focusing on transportation mode

We have developed a prototype mobile phone application that implements a novel transportation mode detection algorithm. The mobile phone application runs in the background and continuously collects data from the built-in acceleration and network location sensors. The collected data is analyzed by the transportation mode detection algorithm and automatically partitioned into activity segments. A key observation of our work is that walking activity can be robustly detected in the data stream. Therefore it is used as a separator for partitioning the data stream into other activity segments. Each vehicle activity segment is then sub-classified according to the type of taken vehicle. Our approach yields high accuracy at a low sampling interval and does not require GPS data. Therefore, device power consumption is minimized.

- Design and implement an effective user interface for contributing and sharing

In order to make crowdsourced data collection effective, mass participation is essential. Therefore it is essential to attract users and to keep them interested in an application. Thus, we will introduce the possible alternatives; show how to effectively deliver and visualize the users' information, how to give benefits to users in return for their contributions, and suggest what kind of social interactions can be implemented to induce more participation.

FUNDAMENTAL GOALS AND CONCLUSIONS

Our goal is to enable people to share urban information at any time through the crowdsourcing urban simulation platform [5]. The information will be returned to the citizens to support their sustainability-aware life. The simulation platform also gives a chance not only to compare each other's levels of sustainability, but also to give self-satisfaction through an altruistic contribution for a sustainable future. Thus, people shall utilize the simulator in order to predict their individual or cities' future sustainability. Meanwhile, the user data will be collected and delivered to the central server in order to analyze the urban sustainability.

We present the methods collecting urban data using smartphone and activity classification from the acceleration and location data, and further, the user interface and user benefit are suggested to give a motivate for voluntary participation. Consequently, we can measure the urban sustainability based on a real human interaction, and compare individuals as well as cities. The whole process of this research is presented as a new paradigm of an urban simulator that reflects the urban complexities and the inconstant human mind changes.

REFERENCES

[1] *Crowdsourcing: The term „crowdsourcing“ is a neologistic portmanteau of „crowd“ and „outsourcing,“ first coined by Jeff Howe in a June 2006 Wired magazine article „The Rise of Crowdsourcing“ (Howe 2006). Howe explains that because technological advances have allowed for cheap consumer electronics, the gap between professionals and amateurs has been diminished. Companies are then able to take advantage of the talent of the public, and Howe states that „It's not outsourcing; it's crowdsourcing.“ (Wikipedia)*

[2] Aiberti, M. (1996). „Measuring urban sustainability.“ *Environ Impact Assess Rev* 16: 381-424.

[3] Bell, S. and S. Morse (2008). *Sustainability indicators: measuring the immeasurable?*, Earthscan/James & James.

[4] Brabham, D. (2009). „Crowdsourcing the public participation process for planning projects.“ *Planning Theory* 8(3): 242.

[5] Halatsch, J., A. Kunze, et al. (2010). „ETH Future Cities Simulation Platform.“ *The Design of Material, Organism, and Minds*: 95-108.

A cellular automaton model for lane formation in bidirectional pedestrian flow

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In a pedestrian crowd it happens often that not all people have the same destination. Even opposing desired walking directions in pedestrian dynamics are the rule rather than the exception. When this is the case, one usually observes that the pedestrians segregate into distinct lanes where each lane contains only people with equal walking direction. This lane formation process is a well known emergent behavior in bidirectional pedestrian flow. But it can also be observed in some physical systems, e.g., in a binary mixture of oppositely charged colloidal particles that are driven by an external field [1]. Those systems with counterflow and lane formation are very interesting from a physical point of view: They are typical examples for self-organization processes and spontaneous symmetry breaking. Additionally, one can often observe non-equilibrium phase transitions and hysteresis behavior. Therefore, they were analyzed quite frequently in physics, but in pedestrian dynamics it is not much known quantitatively about this phenomenon.

For many models the occurrence of lanes is used as a test for the realism, but the statements are only that lanes are present in the system. A more detailed description of the formation process and the properties of lanes are very rare. Furthermore, simulations of pedestrian counterflow are often performed to analyze a so-called "jamming transition" [2], i.e., the focus is not on the lanes but on the jams in the system. But there is no empirical evidence that such a transition should occur in reality. In general, comparisons with empirical data concerning counterflow are extremely rare. This is related to the fact that up to now also the empirical situation is not very satisfying.

Here we analyze lane formation in a two dimensional cellular automaton for pedestrian dynamics. The model is based on the floor field cellular automaton model [3]. It divides the space into discrete cells and represents the pedestrians by particles on the cells. The basic interaction comes from the constraint that each cell can be occupied by at most one particle, but the important feature in regard to lane formation is the „dynamic floor field“. It can be interpreted as a virtual trace which indicates the cells which were occupied by a particle in the nearby past. This trace has an attractive effect to particles of the same desired walking direction. The effect is that the particles tend to follow each other, which is sufficient to create lanes. But at large densities this basic model becomes unrealistic: The dynamics is too much influenced by collisions between particles and for larger densities the system always evolves in a complete jam.

As a consequence one has to introduce additional mechanisms in order to avoid jams more effectively. One of them is to give the virtual pedestrians the ability to look ahead. When pedestrians are in a counterflow, they usually try to avoid collisions with other pedestrians by estimating the prospective route of pedestrian with opposite walking directions. This behavior can be imitated in this model by

introducing an additional “anticipation floor field”. It indicates the space which is most likely to be occupied by particles in the nearby future and has a repulsive effect to particles of the opposite desired walking direction. Another extension of the basic model takes into account that pedestrians are able to walk past each other even if there is very few space, i.e., if the available width is less than two cells (=0.8m). They are for instance able to turn sideways such that the contact area becomes smaller. This is included in the model as the ability of two particles to swap their position under certain conditions.

To quantify the lane structure, we make use of a laning order parameter, which has been used already by Rex and Loewen to detect lanes in a system of oppositely charged particles [4]. This can help to estimate very easily under which conditions (model parameters, environment, etc.) lane formation is possible and gives new insights into the phenomenon.

Furthermore, we compare the results of the model with empirical data from a counterflow experiment [5] which was performed recently within the project „Hermes“. Data for the flow-density relationship were collected with high accuracy. We calibrate the model parameters such that the data are reproduced. In addition, there were two versions of the experiment. In the first version, the participants get no instruction about which of two possible exits (left or right) they have to choose. One observes a complete segregation of the two opposing streams and lanes are formed immediately after the beginning of the experiment and stay stable the whole time. In a second version, they were told to choose an exit according to a number they got before the experiment: Odd numbers exit to the left, even numbers to the right. One still observes lane formation in this version, but the lanes are now unstable and their number increases. This behavior can also be reproduced by the model with the parameters obtained from the fundamental diagram.

REFERENCES

[1] J. Dzubiella, G. P. Hoffmann and H. Loewen, *Lane formation in colloidal mixtures driven by an external field*, *Phys. Rev. E*, Vol. 65 (021402), 2002

[2] Takashi Nagatani, *Freezing transition in bi-directional CA model for facing pedestrian traffic*, *Physics Letters A*, Volume 373, Issue 33, 2009

[3] C. Burstedde, K. Klauck, A. Schadschneider and J. Zittartz, *Simulation of pedestrian dynamics using a two-dimensional cellular automaton*, *Physica A*, Volume 295, 2001

[4] M. Rex and H. Loewen, *Lane formation in oppositely charged colloids driven by an electric field: Chaining and two-dimensional crystallization*, *Physical Review E*, Vol. 75 (051402), 2007.

[5] J. Zhang, W. Klingsch, A. Schadschneider, A. Seyfried, *Ordering in bidirectional pedestrian flows and its influence on the fundamental diagram*, *arXiv:1107.5246v1*, 2011.

Pedestrian map matching using WiFi traces

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In this paper, we will present the data collection methodology and a map matching algorithm adapted for pedestrians and passive WiFi traces.

Gathering data about pedestrian localization and tracking is difficult, in particular indoor and on a large scale. Cameras allow only a small area to be covered. GPS devices do not work indoor and face problems with distribution and access to the data of a large enough population. For a whole transportation hub or a commercial center, it is often not technically appropriate and socially accepted. These data are important for route choice modeling, description of congestion, efficient design of new facilities, and travel guidance and information systems.

We propose to use WiFi traces to track pedestrian paths. This data collection works indoor, is not invasive for the user, and works properly for large fields of observation. WiFi traces allow for the localization of mobile devices and thus of their users, but are scarce and fuzzy. Since WiFi traces are not necessarily related to the pedestrian network, we need to develop a map matching methodology adapted to the data and to the pedestrian context. Our approach offers a way to define pedestrian paths indoor from WiFi traces. We will test it on the Ecole Polytechnique Fédérale de Lausanne (EPFL) campus.

EPFL Campus hosts 11'800 persons, including 7600 students and 4200 employees. Different types of facilities are distributed on 55 hectares. Like many public and private buildings, EPFL is extensively covered by WiFi with 789 access points. It allow us to track pedestrians on the whole campus. For our experiments, we use the routing tool for pedestrians available at EPFL (<http://plan.epfl.ch>) as a pedestrian network representation. Unlike traditional route guidance map services, it also takes into account the floors and stairs in the buildings.

We collect logs of campus members from the WiFi access points. We already have access to one data set and we plan a second data collection. The first data set gives the location of the access point to which a user is connected. In the second data collection, we collaborate with Cisco in order to localize more precisely the users. We use the signals received by all access points around the user and not just the one the user is connected to. Some of these logs are static devices, others are quasi-mobile used only in a few specific places on campus (like laptops in classrooms and at the library), but there are also some mobile devices such as smartphones. It will allow us to track pedestrians on the campus. The precision is quite low (10 meters radius in 90% of cases, 5 meters 10% of remaining cases, depending on the context), but it works in the buildings, where most of the trips take place where the GPS devices do not work. This method of collecting data has several advantages over device-centered processes like the

ones using smartphones, since it doesn't need to have formal acceptance from the users. This process is transparent for the users, and it also works for the users that are not authorized to connect to the system. If an external visitor comes to EPFL, even if he doesn't have the credential required to connect to the WiFi network, his smartphone will announce its MAC address, which is a unique identifier and therefore allows us to track each device. The MAC address is anonymized by EPFL IT Department in order to guarantee privacy.

The poor quality and the scarcity of WiFi localization precludes the use of traditional map matching methods. We plan to adapt a probabilistic map matching method recently developed in our lab for Smartphone GPS data (M. Bierlaire, J. Chen and J. P. Newman, Modeling Route Choice Behavior From Smartphone GPS data, Technical Report 101016, Transport and Mobility Laboratory, EPFL, 2010). We will generate a set of potential true paths and associate a likelihood with each of them. This method proposes a framework based on measurement and structural equations adapted for fuzzy and scattered data.

We will match a set of paths with WiFi traces. For every individual, the algorithm considers each WiFi trace chronologically. At each iteration, it generates a set of path candidates topologically extending the previous one. This extension is not made with one arc but with many. All these arcs are in the domain of data relevance (a concept introduced by Bierlaire and Frejinger in 2008 in an article in Transportation Research Part C) of the WiFi trace, depending on the precision of the measurement. For each arc in this domain and each end of path in the previous set of path candidates, the algorithm connects them with the shortest path.

Then we update the likelihood of each new possible path. For this purpose, we will use a probabilistic measurement model. It computes the probability that an individual with a mobile device could have generated a sequence of WiFi logs while following a given path. It is based on a structural model and a measurement model, which captures the movements of pedestrians and the traces of the WiFi access points respectively. Both will need to be adapted for pedestrian dynamics and WiFi traces.

The possible applications of this methodology with WiFi traces are potentially large. It will be used on campus, but it could help to understand pedestrian behavior with a low cost in data collection for transportation hubs, commercial centers and maybe even for city centers (e.g. shopping street segments) or for mass events, if they are covered by WiFi.

Specific requirements for the egress simulation of large scale outdoor events

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INTRODUCTION

Egress simulation for large scale outdoor events is a challenge for egress simulation. This holds with respect to method and interpretation and assessment of results. The aim of this contribution is to convince the reader that egress simulation can make a valuable contribution to increase safety (and comfort of visitors). To this end, the limits of the application of egress simulation are addressed as well as the connection to fire safety engineering and safety concepts. Without being embedded in such a larger context, the simulation results are useless.

Simulation programs are tools like CNC machines. Neither the aim of its application nor the interpretation and assessment of results are created in the simulation. Both aspects have to be provided from the outside (by the user, the event manager, the authorities, etc.).

If an evacuation analysis is able to provide a substantial contribution to the planning of an event can be decided by the persons who are responsible for the planning and safety. If an event is safe must be decided by whom who is responsible for the assessment of the results or the issuing of a permit of conductance. This issue will be addressed in detail in section 5 at the end.

LARGE SCALE EVENTS

Large scale events are a challenge for safety and security staff. In Germany, a special safety concept is required. After the Loveparade disaster in Duisburg, the ministry of the Interior of the state of North-Rhine Westphalia issued the following decree: [7]:

“In the context of the events at the Love Parade 2010 in Duisburg, the following clarification concerning the process of permission is given: For the state government, the following has foremost priority:

- The safety concept for large scale events must be rendered thoroughly and in consent with all stakeholders.
- The authority which is responsible for the permission must ensure the participation of all other relevant authorities in a transparent and comprehensive process.

A safety concept is required according to SBauVO NRW §43 for venues with more than 5000 visitor spaces.

It might be necessary for smaller venues, too, depending on the infrastructure, the relation of the size of the venue to the size of the town.

VALUES AND AIMES

Legal regulations are for the safety of people (respectively citizens) and their rights. Those are: life and health, property and public safety. The building regulations explicitly state “public safety and order, specifically life, health and natural foundations of life”.

To save those goods, specific aims must be defined. Those aims are for their protection:

- The spread of a fire must be hindered (for a certain time)
- The extinction of a fire must not cause damage which is out of proportion

The evacuation of a building or venue is a measure to protect health and safety of inhabitants and visitors. The emergency egress is order to do this. And this, of course, also holds for the evacuation process itself: the egress paths must be dimensioned such that they allow for safe and orderly egress in an emergency situation. But this is not enough for the safety of an event.

There are many further requirements: The German Association of Professional Fire Brigades (AGBF) has issued a checklist comprising nine chapters [1]

1. Introduction
2. Crisis Management / Crisis Team / Crisis Staff
3. Process for safety relevant issues
4. Evacuation / Emergency Egress
5. Massive occurrence of injuries (MANV)
6. Concept for Security Staff
7. Concept for First Responders
8. Concept for Fire Safety Staff (SWD)
9. Appendices
 - a. Checklists
 - b. Guideline for Fire Safety according to 14096 (if applicable)
 - c. Plans for Fire Brigades according to DIN 14095 (if applicable)
 - d. Flucht- und Rettungspläne nach DIN 4844

The Checklist is freely available [1] (in German). The document explicitly states the aim to contribute to fairness between event and venue managers. To this end clear, concise, and reliable information about the requirements for safety concepts is provided. The requirements might cause considerable effort and should therefore be predictable and clearly defined. The safety concept must be agreed upon by the police, fire brigade, ambulance service, etc. This also requires a clear definition of its scope and contents.

LOVEPARADE

The Loveparade disaster happened in Duisburg in June 2010. We will analyze the causes and reasons for the disaster from a systemic perspective and derive “soft” criteria for detecting pitfalls in the planning process.

CONCLUSION

In this section we will summarize the arguments presented in the previous sections. This leads to recommendations concerning the safety of large scale events. The focus is on the planning phase, the assessment of simulation results, the seven myths of mass psychology, and the method of equivalence analysis.

REFERENCES

- [1] *Arbeitsgemeinschaft der Leiter der Berufsfeuerwehren in der Bundesrepublik Deutschland (AGBF): Sicherheitskonzepte für Versammlungsstätten*, 28.03.2008. http://www.agbf.de/f08_loveparade-i01.htm
- [2] *Vabeg Eventsafety GmbH: Referenzprojekt „Reichsstraßenfest Donauwörth“*
- [4] *RiMEA – Richtlinie für Mikroskopische Enfluchtungsanalysen. Version 2.2.1, 8. Juni 2009. www.rimea.de*
- [6] *TraffGo HT GmbH. Informationen zum Umfang des Auftrags der Lopavent GmbH für die Loveparade 2010 in Duisburg (Angebot, Entfluchtungsanalyse und Anlagen) www.traffgo-ht.com/temp/temp-ub1-del122011/ub1.html*
- [7] *Erlass des Innenministers NRW vom 11.08.2010, Az. 71/38.05.01. Wortlaut und Erläuterungen unter <http://www.im.nrw.de/sch/819.htm>*
- [8] *Landtag NRW, Ausschussprotokoll Apr 15/7 vom 04.08.2010. <http://www.landtag.nrw.de/www/www.landtag.nrw.de/portal/WWW/dokumentenarchiv/Dokument/MMA15-7.pdf>*
- [11] *Mamrot D.: Lovaparade Duisburg 2010 – Wi(e)der die normale Katastrophe. Ingenieurforum 3/2010, Seiten 38 bis 41. www.vfdb.de/downloads*
- [12] *Mamrot D. und Blätte H.J.: Loveparade Duisburg 2010 – Vorschlag zu einer neuen Planungsmethode für Veranstaltungen mit Katastrophenpotential. Vfdb-Zeitschrift 4/2010, Seiten 93 bis 95.*
- [13] *Oberhagemann D.: Analyse der Besucherzahlen und der Ereignisse auf der Rampe zum Veranstaltungsgelände während der Loveparade 2010 in Duisburg. (30.07.2010). Vereinigung zur Förderung des deutschen Brandschutzes (vfdb), <http://www.vfdb.de/download/AnalyseLoveparade2010.pdf>*
- [14] *Nanda Wijermanns: Understanding Crowd Behavior. Dissertation, Universität Groningen, 2011. <http://www.evacmod.net/?q=node/2556>*

Analysis of pedestrian walking speed in a developing country: A factorial design study

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ABSTRACT

The direct use of foreign design codes and unavailability of well-recognized local parameters for pedestrian facilities has been a concern in developing countries. In this paper, a study on pedestrian movements on sidewalks in the capital city Dhaka, Bangladesh has been done to identify the contributing factors on pedestrian mean speeds. Basic data on walking speeds and factors that might affect the speeds were collected from 1,440 pedestrians by a photographic procedure of video recording. Factorial Design with Mixed Levels was used. Results show that walking speeds are greatly affected by pedestrian age, gender and width/density of the facility. Bangladeshi pedestrians are slower than those of Western countries, but are faster or alike compared to some Asian counterparts. Such finding does not validate the sustainability of the adoption of foreign design and parameters for pedestrian facilities in Bangladesh. The results of this analysis can be used as a guideline for developing design codes for local pedestrian facilities.

INTRODUCTION

To reduce environmental pollution, pedestrianization has become an integral part of sustainable modern urban design. To achieve so, pedestrian facilities should be planned and based on the concrete information on user characteristics, travelling patterns and objectives of pedestrian flow. The smooth movement of pedestrians is affected by a number of factors including gender of pedestrians, and location of walking facility[1], width of the walking facility[2], baggage carrying capacity[3]. Pedestrians are the most vulnerable group in Dhaka City when it comes to road accidents, as they constitute 51 percent of the victims of traffic fatalities [4]. This apprehension motivated the current study for statistical analysis of pedestrian individual speed variation on sidewalks in Dhaka, Bangladesh and to examine the influence of some factors supposed to affect the speeds.

METHODOLOGY

Some particular locations were selected for data collection. Observed movement of pedestrians were bi-directional with no entry from or exit to other walkways and pedestrians were with different trip objectives. A photographic procedure was used to collect the basic relevant data of pedestrian movements. Data on pedestrian movements at selected locations were recorded during peak and off-peak periods on three typical weekdays in September of 2011 under clear and dry weather condition.

Combination of the levels of the independent variables age, gender, carrying baggage and location made 36 cells. The analysis of variance (ANOVA) for Factorial Design with Mixed Levels was used to analyse the influence of the chosen variables on the walking speeds of pedestrians. In cases where the null hypothesis was rejected, the least significant difference (LSD) method was used for pairwise

comparison of level-means. All tests were done at 1 or 5 percent level of significance. SPSS (Statistical Package for Social Science) was used to analyse the collected data

MAIN RESULTS

Table 1: List of pedestrian mean speed in different countries

Continent	Country	Author	Pedestrian mean speed(m/sec)
Asia	Saudi Arabia	[5]	1.08
	India	[6]	1.20
	China	[7]	1.20
	Bangladesh		1.20
	Thailand	[1]	1.22
	Singapore	[8]	1.23
Europe	England(UK)	[9]	1.31
North America	USA	[10]	1.47
	Canada	[11]	1.40

Pedestrian mean walking speeds from different countries (which also include the result of present study) are listed in Table 1. Surprisingly, the mean speed of Bangladeshi pedestrians, 1.20 m/sec, is equivalent to the mean speeds of Indian and Chinese pedestrians. Bangladesh is adjacent to India and linked with China by India. This finding might suggest that socioeconomic concord among the pedestrians has a great influence on walking behaviors. It also bears out that Bangladeshi pedestrians are slower than those of Western countries, but are faster or alike compared to some Asian counterparts. Such findings do not validate the sustainability of the adoption of foreign design and parameters for the pedestrian facilities in Bangladesh. Hence an appropriate pedestrian design standard is very necessary for Asia continent, particularly for South Asia.

From the ANOVA, it was found that all main factors -age, gender, location (i.e. width of the location) and baggage -and two interactions gender-baggage and gender-location significantly affect the walking speeds of pedestrians at 1 percent.

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REFERENCES

[1] Tanaboriboon, Y. and J. Guyano, *Analysis of pedestrian movements in Bangkok. Transportation Research Record*, 1991(1294).

[2] Mitchell, D.H. and J. MacGregor Smith, *Topological network design of pedestrian networks. Transportation Research Part B: Methodological*, 2001. 35(2): p. 107-135.

[3] Fruin, J., *Designing for Pedestrians: A Level-of-Service Concept. New York Metropolitan Association of Urban Designers and Environmental Planners. Highway Research Record*, 1971.

- [4] Rahman, M., *Respecting the Rights of Pedestrians*, in *Dhaka Courier* 2010: Dhaka.
- [5] Koushki, P.A., *Walking characteristics in Central Riyadh, Saudi Arabia*. *Journal of transportation engineering*, 1988. 114(6): p. 735-744.
- [6] Victor, D. *Pedestrian traffic management in Indian cities*. in *International 5th conference on transport research*. 1989. Yokohama, Japan.
- [7] Lam, W.H.K., J.F. Morrall, and H. Ho, *Pedestrian flow characteristics in Hong Kong*. *Transportation Research Record*, 1995(1487): p. 56-62.
- [8] Tanaboriboon, Y., S.S. Hwa, and C.H. Chor, *Pedestrian characteristics study in Singapore*. *Journal of transportation engineering*, 1986. 112: p. 229.
- [9] Older, S., *Movement of pedestrians on footways in shopping streets* 1968: *Traffic engineering & control*.
- [10] Hoel, L.A., *Pedestrian Travel Rates in Central Business Districts*. *Traffic engineering*, 1968. 38: p. 10-13.
- [11] Morrall, J.F., L. Ratnayake, and P. Seneviratne, *Comparison of central business district pedestrian characteristics in Canada and Sri Lanka*. *Transportation Research Record*, 1991(1294).

Poster exhibition

Unsorted list

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Scalable evacuation simulation and visualization using GPU computing

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Frozen shuffle update in simple geometries: A first step to simulate pedestrians

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Comparison of evacuation simulation models

An innovative scenario for pedestrian data collection: the observation of an admission test at the University of Milano-Bicocca

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In the context of pedestrian and evacuation dynamics, one of the most relevant topic is related to the difficulty in data collection about this phenomenon [1, 2]: these data represent useful information to characterize events and situations, but they are also necessary to validate modelling and simulation studies of pedestrian and crowd dynamics. From a methodological point of view, experiments and observations are the more suitable techniques to collect data: in this work we chose to perform an observation of a real event, the admission test of the University of Milano-Bicocca, which took place in September 1st, 2011.

This survey was aimed at gathering empirical data related to pedestrian and group dynamics in a situation of medium-high density, in the vein of previous observations and modelling proposals [3]. The survey consists of a quantitative data collection, based on a people counting activity supported by video analysis of the event, with the final aim of developing and validating behavioural models and what-if scenario simulations. The analysis is focused on two relevant aspects of the overall dynamics: composition and behaviour of groups of pedestrians and proxemic behaviour [4], chosen as an analytical indicator of crowd behavioural dynamics, thanks to its ability to model inter and intra-group relationships in high-density situations based on the regulation of spatial distance. In situations of high-medium density, the proxemic behaviour of walking groups is characterized by typical patterns of spatial distribution (line-abreast, V-like, river-like patterns) [5], depending on the psychological bonding and the need of preserving the possibility of (also non verbal) interactions among members, the need to avoid physical contact with others, and the features of the group's members (e.g., gender, age, and so on) [6].

In this context, the aim of the case study was to observe individual and group pedestrian behaviour before the opening time, and during the entry process in the venues of the admission test to the Faculty of Psychology to the University of Milano-Bicocca, which was attended by about two thousand people (2094 students, including 437 males (29%), and 1657 females (79%)). The data collection phase was performed by means of unobtrusive observation and head counting activity from different planned locations (that were determined after a preliminary on-site visit in order to capture flows from all access points), and it was focused on: generalized counting of pedestrian flow, group size, group spatial arrangement (degree of alignment and group cohesion), group walking speed, and formation of queues. To ensure the validity of the research, in addition to the presence of redundant observers and supervisors, video-recording instruments were also employed during the process of data collection. In the context of pedestrian data collection, observations are usually performed in transport places, such as train stations and airports [7], and commercial places, such as shopping malls and commercial walkways [3]. For this reason, the analysed scenario is an innovative case study. Moreover, even if the

admission test is an individual task, excluding group participation, the data analysis underlines that more than 65% of the observed incoming flow was composed of groups, and, in particular, of couples (77%), triples (19%), and groups of four members (4%). An on-going data analysis, related to a selected portion of the pedestrian flow, is focused on the relationship among: walkway level of service, social density, group size and shape, gender, and walking speed.

Starting from this work, the paper will give a complete description of the survey activity, starting from a exhaustive theoretical discussion about the relationship among crowd, pedestrian groups and proxemics, and a systematic description of the case study: the scenario analysis, the methodological approach, the data collected, and the performed analysis. The presented case study can be useful to support developments in the modelling crowd and pedestrian dynamics, by means of simulation tools: the data analysis will be exploited to implement several what-if scenarios related to the observed phenomenon. Thanks to the collaboration with the authority of the University of Milano-Bicocca, the results achieved can be a useful starting point to design alternative strategies related to a more efficient management of people who attend every year the admission test. The results of this work will support the development of policies and guidelines for the management of attendees, the re-organization of the physical layout of the environment (by means of the use of barriers or signposting) in order to reduce queuing times.

REFERENCES

- [1] Peacock, R. D., Kuligowski, E. D., & Averill, J. D. (2011). *Pedestrian and Evacuation Dynamics*. Springer Verlag.
- [2] Resilience, U. K. (2009). *Understanding Crowd Behaviours*. Cabinet Office, London.
- [3] Moussaïd, M., Perozo, N., Garnier, S., Helbing, D., & Theraulaz, G. (2010). *The walking behaviour of pedestrian social groups and its impact on crowd dynamics*. *PLoS One*, 5(4), e10047.
- [4] Hall, E. T. (1966). *The Hidden Dimension*. Doubleday, New York.
- [5] Karamouzas, I., & Overmars, M. (2010). *Simulating the local behaviour of small pedestrian groups*. *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology*, pp. 183-190.
- [6] Costa, M. (2010). *Interpersonal Distances in Group Walking*. *Journal of Nonverbal Behavior*, 34(1), pp. 15-26.
- [7] Schultz, M., Schulz, C., & Fricke, H. (2010). *Passenger Dynamics at Airport Terminal Environment*. *Pedestrian and Evacuation Dynamics 2008*, pp. 381-396.

Scalable evacuation simulation and visualization using GPU computing

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Real-time simulation tools are effective for interactively analyzing evacuation behaviors. However, computing and visualizing massive agent-based crowds in real-time is a computationally intensive task because most algorithms for calculating the interactions among all the agents. In previous work, researchers have reduced this complexity by employing special data structures, such as mesh models or network models. Additionally, researchers have significantly increased computational performance by adapting existing CPU-oriented algorithms to parallel processing architectures. A promising new parallel architecture uses commodity graphics processing units (GPUs) having many cores, offering the performance benefits of parallel processing at a low cost. This was the advent of the movement called GPU computing. Using this technology, it is now easier to design scalable agent-based simulations that can be executed on GPUs. In this paper, we will describe our novel approach to real-time visualization of crowd flow using a scalable evacuation simulation that is suitable for execution on GPUs.

The evacuation simulation uses an agent-based system. Namely, an evacuee is modeled as an agent. The modeling of each agent's behavior consists of (1) the route choice model: setting a destination and calculating the route; and (2) the crowd walking model: approaching the destination and avoiding collisions with other agents and obstacles. In our research, we implemented a shortest route choice model and the social force model [Helbing et al, 2000].

Conventional methods implement agent-based modeling using CPU-oriented algorithms. The social force model that we implemented previously was also calculated on the CPU, with the agents rendered on the GPU only after they have updated their position. However in recent years, the use of GPUs for general purpose computing has become a new area of research. In our new simulation, the social force model operations were executed on a GPU using CUDA technology, which is a parallel-processing architecture for GPUs with many cores. Specifically, one thread is allocated per agent to calculate the social forces on that agent. Although CPUs can only concurrently execute one thread per core, CUDA can run tens of thousands of threads simultaneously. Thus the GPU's computational power is sufficient for updating the behavior of scalable agent-based crowds in real-time.

To evaluate the performance of our simulation method, we ran two implementation of the simulation. The first was executed on a GPU, and the second was executed on a CPU. The same algorithm and data structures were used in both simulations. These tests were conducted on an Intel Core i7 930 2.80 GHz CPU and an NVIDIA GeForce GTX 460 GPU. These tests were executed for each implementation type, varying only the number of agents, which ranged between 1000 and 10,000. It was found that the GPU version had better scalability than the CPU version. For example, at 10,000 agents, the GPU version was approximately seven times faster than the CPU version. Moreover, it can be clearly observed that

the performance of the GPU version was sufficient to sustain interactive frame rates for rendering complex models of agents and buildings. Such interactive visualization is effective for interactively analyzing evacuation behaviors in the trial-and-error stage of creating an evacuation plan.

Before applying the evacuation simulation to a large space, we verify the crowd walking component of the social force model using a much simpler space by calculating the relationship between crowd walking speed and crowd density. As a result, an increase in the crowd density causes a decrease in walking speed. This tendency conforms to an empirical model.

As a case study of scalable evacuation simulation, we created an evacuation scenario for a large underground shopping mall in Osaka, Japan. This underground shopping mall has 1,200 retail stores and restaurants, as well as a subway and intercity rail station. Thus this underground area has one of the most complicated space compositions.

As a result, it took 5 minutes to evacuate all the 25,000 people in the large underground shopping mall according to the evacuation simulation. However approximately 80% of evacuees escaped within only 1 minute. Therefore, it is likely that there are areas where the number of staircases is insufficient. Although some might claim that there is no practical use in simulating a situation in which evacuees are uniformly distributed and all evacuees escape through one of the nearest staircases. However, we think this simulation can serve as a guide for analyzing the evacuation of this area.

In this paper, we have described a scalable evacuation simulation that can be executed on GPUs while visualizing crowd flow in a large underground shopping mall interactively. Our simulation has demonstrated that the social force model, which is used in this simulation to model the walking behavior of the agents, is a reasonable approximation of real crowd walking behavior in terms of walking speed and crowd density. Moreover, we demonstrated that the GPU-based implementation was capable of supporting up to 25,000 agents at an interactive frame rate using current graphics hardware and CUDA technology. Therefore we have shown that this simulation has potential as an effective tool for designing and evaluating large urban environments.

REFERENCE

Helbing, D., Farkas, I. and Vicsek, T., „Simulating Dynamical Features of Escape Panic“, Nature (2000), Vol.407, pp.487-490

Cognition-oriented simulation of pedestrian dynamics: Perceptually driven social force model

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Simulation models of pedestrian dynamics have recently become important tools of planning and design in many areas of architecture and civil engineering. They aid the architect or engineer in his or her attempt to create secure and comfortable pedestrian facilities and environments. The increasing importance of pedestrian simulations emphasises the need of accurate and reliable simulation models. For the simulation of pedestrian dynamics a wide variety of different models exists representing these dynamics analogous to physical systems. Despite the fact that most of the models currently in use reproduce many of the available empirical observations of pedestrian dynamics relatively good on a qualitative level, reliable results on the quantitative level are still missing. The physical origin and nature of the observation strategies and the modelling approaches are responsible for the incomplete and insufficient representation of the observed system. Hence, the complicated behaviour of human beings cannot be realistically reproduced by just applying a physical scheme of stimulus and reaction.

A cognition-oriented approach to modelling pedestrian motion can take into account the flexibility of human behaviour. Here significant research is needed for a realistic simulation of pedestrian behaviour that is not rigidly coupled to the stimuli of the outside world, but rather a result of the internal cognitive processes. The reproduction of the missing flexibility of the human cognition and the resulting behaviour is an important development for compensating the limited analogy between pedestrian dynamics and physical processes in the mathematical models so far in use. A paradigm change should be undertaken, in which a pedestrian is not merely an observed moving physical object any more, but rather an observed intelligent human being. The findings and methods of cognitive science provide a sound and well-grounded basis to cope with this challenge. The main purpose of cognitive science is to explain the internal processes that take place inside a human being after receiving a stimulus and before taking the originated or triggered reaction. A systematic adaptation of the methods and findings of cognitive science can drastically improve the modelling methodology of pedestrian dynamics and will open the door for further multidisciplinary collaboration with a wide range of disciplines, especially cognitive psychology, architecture and civil engineering, and computer science.

This paper considers modelling the spatial perception of pedestrians as one of the key cognitive activities. Sight and hearing are the primary senses responsible for the spatial perception of the surroundings. External stimuli usually find their way to the spatial cognitive system of a human being through this mental, physiological capability. Hence, spatial perception is an important foundation of the behaviour of pedestrians and has the primary function in facilitating interactions between the individual and its environment. The spatial representation of the environment, so far in use in the current theoretical physical simulation models of pedestrian dynamics, takes a bird's-eye view of the

surroundings. The exact positions, size and motion is represented in a precise euclidean geometry. This representation satisfies the purpose of describing a motion model, but it does not help to facilitate the modelling of a perceptually guided interaction between individuals and their environment. Therefore, a spatial representation from a pedestrian standpoint or perspective is needed. Each individual pedestrian interprets the spatial information he perceives in terms of his own subjective frame of reference. In contrast to the precise representation used in motion models, the desired spatial perceptual representation should take into account the subjective interpretation of the surroundings and the associated state of mind or feeling emphasising internal processes not resulting directly from the stimulus input. Modelling the spatial perception on the basis of such an egocentric spatial representation will be a starting point of cognition-oriented simulations of pedestrian dynamics.

In this paper a mathematical model of the subjective human spatial perception will be presented. Motivated by the fact that human cognitive activities are approximate rather than precise in nature, the model is based on the theory of fuzzy sets. This pedestrian-centred dynamic representation of the surrounding is then integrated in a modified version of the well-known social force model to result in a perceptually driven motion model of pedestrians. Bridging the gap between the flexibility of human representations and the precision and clarity of physical or computerised representations is a major advantage of this approach. Several improvements in simulating the individual and collective behaviour of pedestrians are expected. A validation alongside a sensitivity analysis of the resulting perceptually driven social force model will also be provided. The performance of the model is evaluated. Its capabilities, limitations and possible further improvements will be discussed. The validation process is making use of qualitative and quantitative comparisons with empirical data reported in the literature. The paper will end up with a discussion of the achieved results and a presentation of the drawn conclusions. The focus of future investigations, such as, the possibility of modelling the perception related effects of stress situations associated with the so-called "Panic" behaviour, and the possibility of simulating pedestrian dynamics in dark or smoke-filled environments in more realistic way, will be highlighted among other further future research work.

Interaction behaviour between individual pedestrians

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Recently, public places such as shopping malls and public transport terminals have become more and more crowded due to increased population size and mobility. The ease of use of these places for pedestrians depends to a large extent on the pedestrian density in peak hours. Since space in these densely occupied areas is highly valued, the use of every square meter has to be evaluated carefully.

Planners and designers of pedestrian infrastructure have a large need for accurate evaluation tools. Very promising tools to fulfil this need are microscopic pedestrian simulation models. These can provide an objective assessment of a pedestrian facility and quantitatively predict critical areas and bottlenecks in the facility's design.

An important feature of these microscopic models is the ability to represent individual walking behaviour in a realistic way. An essential element in individual walking behaviour is the response to the behaviour of other pedestrians that are encountered in the walking area. This is referred to as interaction behaviour. Especially the interactions between individual pedestrians appear to be poorly simulated on the microscopic level. This paper describes these interactions in more detail using empirical data.

To identify and quantify pedestrian interaction movements we have collected detailed data in laboratory experiments. In laboratory experiments the external conditions and other factors that influence interaction behaviour can be controlled and the effect of these separate factors can be deduced more easily. With a smart experimental design the amount of information that can be obtained from a laboratory experiment can be maximized. Based on a literature study, we have selected the following experimental variables: age, body size, gender, free speed, travel purpose, manoeuvrability, number of pedestrians and walking arrangements. First, observations on the intended path have been performed, where pedestrians are not hindered by other pedestrians. Then, pedestrian trajectories for the interaction situations are measured. Walking outside of the intended path in unhindered walking implies that interaction movements are performed. Interaction movements can be quantified by measuring lateral and longitudinal evasion from the mean trajectory and mean speed graph in unhindered walking. The following experiments have been performed (N = Normal, H = Hurry, O = nO reduced manoeuvrability, R = Reduced manoeuvrability):

A group of twelve participants (six men and six women) participated in the experiments, in order to have sufficient repetitions of similar encounters. The length of the walking stretch is 20 meters, where interaction is expected to happen halfway this length, i.e. at 10 meters from the initial starting position.

Using the pedestrian trajectories, very detailed behavioural analyses have been performed, both for the unhindered and for the interaction situations. For unhindered walking, we have studied walking speed, step length and step frequency. With this knowledge, we are better able to identify whether the behaviour during interactions is due to natural deviation, or whether it should be attributed to the interaction. For interaction behaviour, we have looked at lateral and longitudinal interaction movements, and we have compared for the various interaction situations and pedestrian characteristics passing side and extent of evasion (both in lateral and longitudinal direction). In the paper, we will present the extensive analyses, here we limit ourselves to our findings.

It has been found that individual pedestrians perform movements that are related to interaction in 88% of all occasions when they meet another pedestrian. These interaction movements consist of lateral and/or longitudinal evasive manoeuvres to avoid a collision. These movements can be interpreted as some gallantry towards other pedestrians.

The side where pedestrians pass each other is found to be dependent on the direction of approach. For crossing situations the side of approach has no influence on the passing side. However, if the angle of approach increases and the situation comes closer to bidirectional, pedestrians prefer to pass each other on the right hand side. In the bidirectional situation pedestrians strongly prefer passing on the right hand side. It is also found that walking in a hurry increases the probability of passing in front of another pedestrian in crossing situations. Meeting a small group of two pedestrians increases the probability of passing at the back.

The passing side and the direction of approach (i.e. bidirectional or crossing) mainly determine the direction and extent of evasion from the individual mean walking path and from the individual mean walking speed. Pedestrians seem to prefer larger lateral evasion in bidirectional situations and larger longitudinal evasion in crossing situations. Moreover, men laterally evade more than women and hurried pedestrians laterally evade more than normally walking pedestrians. It seems that hurried pedestrians are either granted 'right of way' in an early stage of the interaction process or that they take the initiative in interaction themselves. Finally, the extent of evasion is larger when small groups are encountered.

Shared space simulation based on social forces and distance potential field

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The design of public space in cities provides opportunities for leisure, social interaction and physical activities which influence the travel pattern, road congestion and traffic delays. Urban design moves towards changing the way streets function by reducing the dominance of vehicles. In this new urban design principle, a variety of standardised mechanisms, control systems and markings are reduced creating a strong relationship between the street and its surroundings. Thus, shared space users need to rely on eye-contact, negotiate their right of way with other traffic participants, and drive more carefully in order to correctly read situations. There is a need for a quantitative assessment of shared space principles in order to identify the conditions under which sharing street space with pedestrians is a feasible alternative to traditional street designs. As a part of this aim, a mathematical model is proposed to describe the main behaviours of shared space users based on social forces. In addition, a Distance Potential Field using the flood fill method is generated for finding the shortest path towards the target destination. Real data from three shared space environments: Brighton (United Kingdom), Haren (The Netherlands) and Bohmte (Germany) are used to support the behavioural assumptions of the simulation and will be used to calibrate model parameters in the future.

The proposed mathematical model is based on the Social Force Model (SFM), which explains the acceleration of an object (like a pedestrian) in a two-dimensional space as the resolution of forces exerted by neighbouring objects (such as other pedestrians, cars, and fixed obstacles) and the target (destination). The SFM resembles a car following model extended to two dimensions, which has the potential to describe gap acceptance behaviour as well. An advantage of the SFM is that its parameters are associated with meaningful quantities that can be measured. In addition, the SFM can be modified to allow new objects and, different behaviours or actions to be included. This is accomplished by changing the value of parameters, such as the desired direction of movement. The resulting model allows multi-directional flows to be simulated. These factors all contribute to the choice of the SFM as the mathematical basis for the simulation and evaluation of shared space schemes.

Since pedestrian movement and car traffic coexist within shared space environments, the basic SFM for pedestrians is modified by the addition of new objects representing vehicles. Since cars are restricted with respect to change of direction and lateral movement is not possible, an 'effective factor' is included for social interaction forces as a form factor term. The 'effective factor' varies the influence of forces exerted from different directions and distinguishes between a car-pedestrian or a car-car interaction. Further, there is a relationship between the steering angle and the velocity of a vehicle. Therefore, turning constraints are given to avoid sharp turning behaviours for drivers. There are more subtle behavioural effects as well that influence driver responses. For instance, vehicles tend to pass each other on the left (in the UK) or tend to queue rather than overtake in congestion. These aspects are included

by assigning behavioural rules that adjust parameters of the forces. The model for pedestrians is also modified as they are not only interacting with other pedestrians and boundaries but also with vehicles. Further, a predictor-corrector method called Gear algorithm is used in order to numerically solve the set of ordinary differential equations over time for each mobile object. This method can deal with forces dependent on velocity and position. The Gear's fourth order predictor algorithm keeps two higher derivatives to be able to get a better estimation of the new position and velocity.

Having introduced this microscopic mathematical foundation with the local motion based on social forces, a tactical algorithm is added. This tactical level determines walking or driving paths that human beings are likely to choose under shared space conditions. In fact, the Distance Potential Field is generated separately for pedestrians and drivers to indicate the trajectory of the shortest path to reach the destination. Flood fill dynamics are used to calculate the Distance Potential Field and a combination of Manhattan Metric and Chessboard Metric is used to calculate distances considering all obstacles. The Distance Potential Field is re-calculated for shared space while the simulation runs, each time a vehicle influences the paths of pedestrians within the shared area.

In conclusion, based on the proposed mathematical foundation and the additional tactical level, a c# simulation for shared spaces is created which is capable of facilitating a quantitative prediction of travel patterns. It is shown that the concept of social forces is applicable for modelling the observed movements of shared space users. In addition, the distance and the last direction of movement of shared space users provide enough information to explain their decision making process. The model offers a basis for the understanding of shared space user behaviours and its relationship to space design and traffic management.

Frozen shuffle update in simple geometries: A first step to simulate pedestrians

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Motivated by interest in pedestrian traffic, we introduce a new type of update for cellular automata models, that could be appropriate to model pedestrians in particular at low or moderate densities. In a first stage, we have applied it to a simple model using TASEP lanes.

A TASEP (for Totally Asymmetric Simple Exclusion Process) is a cellular automaton in which particles move on a lattice by jumping from one box to the next one, always in the same direction. This is an exclusion process, so there can be only 0 or 1 particle on each site. Here the TASEP does not have to be totally deterministic, the movements of the pedestrians can occur at some probability different from one, for instance. The positions of the particles can be updated using a parallel scheme (they all move at the same time) or a sequential one (they move one after another). In that case, the updating order can be chosen to follow various rules. We decided to introduce a new type of update scheme. It is called 'frozen shuffle' update, and it consists in updating the particles in a randomly chosen order, which does not change at each timestep but is fixed once for all. The dynamics is then deterministic once the order has been chosen.

This avoids priority issues between pedestrians : the first pedestrian to move will simply jump on its target before the other one. This update also lowers the statistical fluctuations, since all the pedestrians have barely the same velocity when they are not constrained. Besides, in the free flow phase, there exists a direct mapping between the discrete TASEP with frozen shuffle update and a model of moving rods in continuous space and time. We investigate this model analytically, and by Monte-Carlo simulation, for different boundary conditions and geometries.

First, we study it on the one-dimensional ring, the simplest non-trivial geometry. Indeed, after averaging over all possible orders, there are only two macroscopic parameters left : the particle density and the particle current. We find that there is a phase transition for some critical value of the density : the flow is free for small densities, whereas jamming appears for higher ones. We are able to plot the fundamental diagram (particle current as a function of density), and to predict it analytically for an infinite system and compute finite-size corrections near the transition.

Secondly, we use open boundary conditions for the TASEP lane, fixing the entrance and exit probabilities. Since we now have to create particles, we must now insert them into the already-existing particles update chain. We use the aforementioned equivalence of the model with a continuous model of pedestrians evolving in a continuous space-time to prescribe how particles are injected in the system. We obtain numerically the bulk density versus the entrance probability and again there is a phase transition between free flow and jammed flow.

It turns out that this transition - which can be predicted analytically - occurs when the entrance and the exit probabilities are equal, as usual for other update schemes, though it is not so straightforward here. Indeed, in contrast with other update schemes, the current in the jammed phase depends not only on the exit rate, but also on the entrance rate (as the latter has an effect on the update order).

We have considered only the deterministic version of the model, for which pedestrians move with probability 1 when it is possible. The usual maximal-current phase is therefore reduced to a point. We use a domain-wall approach to compute the density profile, which gives us the correlation length and some scaling law near the transition.

Finally, we consider a set of two open TASEP lanes sharing one box, in other words a crossing. We can then vary the two entrance probabilities and the two exit probabilities, and each lane can be either in a free flow regime or jammed. The simplest case is when the system is symmetrical between the two lanes, but we also studied an asymmetric system with exit probabilities set to one (in order to have only the jams created by the crossing and not by exit conditions). Eventually we vary each parameter independently. With this update scheme, we see that the particles tend to form groups that we call platoon, in which particles all move as a whole. We also show that a pairing mechanism between the platoons takes place at the crossing box, enabling us to compute the phase boundaries for large systems, which are coherent with numerics. Doing this, we also derive some other features, such as the density and the exit current in each lane.

In further work, we plan to take into account the width of the corridors through multilane models, and to enlarge the crossing to a bigger square. Our aim would be to understand how macroscopic structures can spontaneously emerge in such systems, and how they are modified for various modifications of the dynamical rules.

REFERENCES

C. Appert-Rolland, J. Cividini and H. Hilhorst. Frozen shuffle update for an asymmetric exclusion process on a ring. J. Stat. Mech., P07009, 2011.

C. Appert-Rolland, J. Cividini and H. Hilhorst. Frozen shuffle update for deterministic totally asymmetric simple exclusion process with open boundaries. J. Stat. Mech., P10013, 2011.

C. Appert-Rolland, J. Cividini and H. Hilhorst. Intersection of two TASEP traffic lanes with frozen shuffle update. J. Stat. Mech., P10014, 2011.

Comparison of evacuation simulation models

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In this paper, different fire safety engineering methods for the calculation of egress times are applied. Since the models are widespread and documented in detail elsewhere, they can be assumed to be representative for the field of egress modelling. Therefore, the focus here is on the comparison of the simulation results. The example of application is an auditorium.

One pillar of fire safety engineering are computer based methods for egress simulation. When assessing variations for complex or existing buildings, prescriptive rules are often not sufficient to cover all relevant aspects and details. This is often the case for buildings like airports, shopping centers, stadia, etc. The basic idea is to prove that the available safe egress time is sufficient, i.e. the required time is smaller. In addition, there must be no threat to personal safety during the evacuation process. The available safe egress time (ASET) is often determined based on CFD simulations or derived from general considerations. The required safe egress time (RSET) consists of at least four phases:

$$\text{RSET} = \text{Detection} + \text{Alarm} + \text{Reaction} + \text{Movement}$$

Since the focus is on the comparison of the model, the first three phases are not taken into account and the focus is on the movement phase. If one wishes to take into account detection and alarm, these times can be added to the movement time. The reaction time can be explicitly put into the simulation models (i.e. as a distribution of individual reaction times) but is also not considered for our comparison.

In this contribution we show a comparison of evacuation simulation results for the following models: Aseri, buildingExodus, FDS+Evac, PedGo. These results are compared to the calculations based on a capacity analysis and the model by Predtetschenskii and Milinski. In summary, six different methods are compared to each other.

In addition to the the results for the evacuation analysis of the building (auditorium), two simple escape route elements were simulated: (1) a 50m hallway of width 2m and (2) a hallway 10m long and 2m wide with an ascending stair. In the final section, criteria for the assessment of egress times and congestion are presented.

The auditorium to be evacuated is 34 m x 29 m x 12 m (L x W x H) and has 20 rows with 32 seats each. Up to 640 persons seating and 360 standing might occupy the venue. There are two stairs in the middle and two stairs at the side. The auditorium has two main entrance doors which lead (in case of egress) to the first floor of the building. The egress route is further via one stair to the ground floor and outside.

The evacuation time is the time when the last person has left the room via either the emergency exits or via the stair leading to the ground floor. I.e. for the escape route via the main entrance doors and the stair to the ground floor, the time is taken when the end of the stair, i.e. the ground floor is reached.

The escape route have been designed according to the German guidelines (Versammlungsstättenverordnung). According to these guidelines, the total width for 1000 persons is required to be 6m. The two main entrance and exit doors (on the first floor leading to a staircase in the foyer) have two meters each. There are two additional emergency exits at the front of the auditorium (on the ground floor) with 2m each. The requirement concerning the maximum length to a safe area is also fulfilled. In the simulation, the emergency egress via escape route 1 (main entrance) and escape route 2 (emergency exits) is compared. Reaction times are not set. The results for the four simulation programs are compared to the capacity analysis and the calculations based on the model of Predtetschenskii and Milinski.

The egress times for escape route 1 are in a range of $\pm 13\%$ around the mean, for escape route 2 from -16% to $+12\%$ around the mean.

Model	escape route 1		escape route 2	
	Time	Congestion	Time	Congestion
Capacity Analysis	304s	main door	298s	emergency exit
Predtetschenski	295s	internal stair	318s	internal stair
buildingEXODUS	382s	internal stair	266s	internal stair
PedGo	348s	int. st., exit	276s	int. st., main exit
FDS+Evac	373s	int. st., exit	239s	internal stair
ASERI	311s	internal stair	311s	emergency exit
Mean	388s	+/- 13%	285s	+16% -12%

The evacuation analysis has two major aims: (1) determine the overall time (RSET) and (2) identify critical conditions during an evacuation.

The times obtained in the different models are deviating about $\pm 20\%$ from the mean value for all six methods and are therefore acceptable.

The identification of congestion is more diverse, i.e. different models identify different „hot spots“. For the analysis of single escape route elements the deviations of the results for different models are more prominent than for the complete building.

Human behavior in stressful situations is even harder to foretell. Therefore, to the knowledge of the authors, there are currently no detailed systematic and quantitative assessment criteria for a safe evacuation. Several criteria, like congestion and delay times, maximum densities and pressures (or forces) are summarized in this paper.

Poster exhibition

Unsorted list

Maria Davidich, Siemens AG, München GERMANY

Waiting zone for real life scenarios. Example a German railway station

Christian Eilhardt, Universität zu Köln, Köln GERMANY

Phase separation in pedestrian traffic: An approach to modelling

Sebastian Kühn, Technische Universität Kaiserslautern, Kaiserslautern GERMANY

Evacuation dynamics influenced by spreading hazardous material

Jan Peter Ohst, Technische Universität Kaiserslautern, Kaiserslautern GERMANY

Minimizing the costs of evacuation paths by decomposing network flows

Jan Dijkstra, Eindhoven University of Technology, Eindhoven NETHERLANDS

Modelling time duration of planned and unplanned store visits in a multi-agent simulation of pedestrian activity in city centres

Jun Zhang, Bergische Universität Wuppertal, Wuppertal GERMANY

Empirical relations for bidirectional pedestrian stream in a corridor

Stefan Holl, Forschungszentrum Jülich GmbH, Jülich GERMANY

HERMES – An evacuation assistant for large arenas

Sebastian Burghardt, Bergische Universität Wuppertal, Wuppertal GERMANY

Analysis of flow-influencing factors in mouths of grandstands

Waiting zone for real life scenarios. Example a German railway station

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Pedestrian stream simulations imitate real life crowd behavior, aiming to reproduce it as close as possible. Their applications range from planning special events, such as concerts and sports, collecting experience with critical situations, such as evacuation, to evaluating the placement of advertisements. The utility value of a simulator depends on how well it reproduces real behaviour in different situations that can occur.

In most simulations, pedestrians are “single minded” and only move towards their targets. However, our observations on a major German railway station during several field experiments show that a significant part of pedestrians do not constantly move towards the targets, but stand still waiting for other people or their trains to arrive. These waiting persons thereby influence the crowd dynamics, sometimes even more than the ones who are walking. For example, a typical observed situation is the following. On Friday evening many persons come to a railway station and wait for their friends and relatives who are coming back home or coming for a visit. Usually, they crowd at the ends of railway tracks. This is a critical location at a short time period after a train arrival when many passengers disembark a train. By staying in these critical locations the waiting persons block the ones who arrived with a train, which results in bottlenecks. Thereby, the standing pedestrians significantly influence the dynamics of a crowd. In order to be able to reproduce these kind of situations, pedestrian stream models should consider not only moving pedestrians, but also pedestrians which are standing or, at least, not moving for certain periods of time.

Here, we propose a model for representing waiting zones applied to pedestrian stream simulation based on cellular automata. The main idea of a cellular automata-based model is: The observed area is split into cells and each cell can either be occupied by some person, obstacle, target or a source, or be empty. We imagine that forces of attraction exist between targets and pedestrians, and that pedestrians are repulsed by obstacles and other pedestrians. These forces between pedestrians, targets and obstacles are expressed through suitable scalar functions: the potentials. With this approach, on each time step pedestrians chose their direction of movement so that their potential decreases.

We improve this model by introducing waiting areas. The waiting area model enables to model pedestrians who not only walk towards their target, but also keep standing. As soon as a pedestrian has reached some pre-defined waiting zone, he/she may choose an arbitrary location within this area and stand there for a determined period of time.

We validate the proposed model on a set of complex real life scenarios taking place on a major German railway station during daytime. The observed behaviour is that there are always some pedestrians that

are walking towards railway tracks and some that are waiting for a train. There are also pedestrians that are waiting in other parts of the station.

An observation survey combines recorded video, extracted footage and a number of field observations on this railway station. The videos have been recorded during peak hours in the morning and in the evening. Several cameras recorded pedestrians in some part of this railway station from a bird's eye view. Traces of individual pedestrians in time and space have been extracted manually from the videos using a tool that allows to manually „click“ their positions on a screen. Usually, a position of a pedestrian was taken as that of his/her head. At this point we have finished analyzing two video recordings, each having a duration of at least 1.5 minutes. The number of pedestrians observed on each video is about 400. The area covered on each video includes several platforms and a part of the station's main hall. All trajectories within the complete area of video observation were extracted and analyzed. The tracking of pedestrians provided information on velocities distribution and density-velocity relation.

Our field experiments included two and a half days of observing the train station from early morning to late evening. During these experiments, the statistics on pedestrian arrival/departure rates, pedestrian walking times at each measurement section and pedestrian waiting times at each waiting area were collected. The collected data was then used to calibrate the simulation model so that the simulated dynamics reproduces the observed one.

We demonstrate several real life scenarios and the influence of waiting areas on a general dynamics of a crowd. We also show how the developed model can be used as a planning tool and simulate several scenarios where the situation becomes critical due to waiting persons blocking the way of others and thereby creating bottlenecks. Thus, the waiting zones play a significant role for pedestrian stream simulation, and various critical situations cannot be adequately simulated without taking the waiting zones into account.

Phase separation in pedestrian traffic: An approach to modelling

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The separation of pedestrian traffic into two phases (not moving and slowly moving pedestrians, respectively) is an effect that can be generally observed, but has barely been studied systematically. The understanding of this phase separation deepens the general understanding of pedestrian dynamics and could therefore improve the design of airports, shopping centers and other crowded areas as well as improve safety during evacuations.

The occurrence of phase separation is a common and well-understood feature in vehicular traffic [1]. There are two distinct phases: A jammed phase with high density and a free-flow phase with cars moving at their desired velocity. This can be reproduced in appropriate models such as the VDR model [2]. By using a "slow-to-start" rule the outflow of the jam is reduced compared to the maximal flow of the system. This leads to a region of non-interacting cars and thus to the free-flow phase. The existence of two distinct phases is connected to the existence of metastable states in the fundamental diagram. For intermediate density values the flow is not a unique function of the density: the free flow branch can spontaneously break down into a congested state. This is called a capacity drop and leads to a hysteresis loop [3].

The situation in pedestrian dynamics is more complicated for several reasons. The most obvious one is the generally two-dimensional nature of pedestrian movement in contrast to the one-dimensional movement in vehicular traffic. Furthermore, collision avoidance is less of an issue for pedestrians – pedestrians bump into each other regularly, cars do not. Finally, the movement of pedestrians is at least potentially influenced by multiple other pedestrians whereas the interaction range in vehicular traffic is very small.

Therefore experiments [4] show a similar, but somewhat different behavior for pedestrians compared to what is observed in vehicular traffic. Firstly, the pedestrian fundamental diagram does not show metastable states similar to the vehicular fundamental diagram. However, the trajectories of the one-dimensional "single-file" pedestrian movement feature two separate phases, namely a jammed high-density phase and a phase of medium to high density with slowly moving pedestrians. To analyze pedestrian phase separation, one therefore has to study microscopic quantities (trajectories), it does not suffice to study the (macroscopic) fundamental diagram. In contrast to vehicular traffic, the distance between pedestrians in the moving phase is small, not allowing them to move with their desired velocity. Both phases consist of interacting particles (pedestrians). The mechanism creating the phase separation therefore differs from a "slow-to-start" rule. The relatively small time-scale as well as spatial scale of the actual measurement do not allow to judge the stability of the phase separation.

We try to understand the emergence of this kind of pedestrian phase separation. Typical pedestrian models such as the social force model by Helbing et al. [5] or the floor field cellular automaton model by Burstedde et al. [6] can successfully describe qualitative phenomena like lane formation and are even used for quantitative predictions. However, they do not feature phase separation! For that reason, we develop a simple cellular automaton model that aims at reproducing the observed phase separation. The transition probabilities of the modeled pedestrians in general depend on their current velocities and on the occupancy of the next two cells in front of them. The model uses a parallel update.

The resulting trajectories of the pedestrians clearly feature two distinct phases, namely a completely jammed phase and a phase in which pedestrians are slowly moving. This phase separation is very slowly decaying into a single congested high density state with slowly moving pedestrians. However, the results are in good agreement with the experimental data when observed over a corresponding timescale. We study several variants of the model and perform simulation runs with varying pedestrian densities, maximal velocities and starting conditions (jammed, homogeneous, random). Furthermore, we discuss possible mechanisms such as anticipation that may generate the experimentally observed phase separation. The analysis of the resulting trajectories will be presented here. Finally, we discuss the general feasibility of cellular automaton models to simulate pedestrian phase separation.

REFERENCES

- [1] A. Schadschneider, D. Chowdhury, and K. Nishinari, *Stochastic transport in complex systems: From molecules to vehicles* (Elsevier, 2010)
- [2] R. Barlovic, L. Santen, A. Schadschneider, M. Schreckenberg, *Metastable states in cellular automata for traffic flow*. *European Physical Journal B* 5, 793 (1998)
- [3] F.L. Hall, B.L. Allen, and M.A. Gunter, *Empirical analysis of freeway flow-density relationships*. *Transp. Res. A*, 20:197 (1986)
- [4] A. Seyfried, A. Portz, A. Schadschneider, *Phase Coexistence in Congested States of Pedestrian Dynamics*. *Lecture Notes in Computer Science* 6350, 496 (2010)
- [5] D. Helbing and P. Molnár, *Social force model for pedestrian dynamics*. *Phys. Rev. E*, 51:4282, (1995)
- [6] C. Burstedde, K. Klauck, A. Schadschneider, and J. Zittartz, *Simulation of pedestrian dynamics using a 2-dimensional cellular automaton*. *Physica A*, 295:507 (2001)

Evacuation dynamics influenced by spreading hazardous material

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In this article, an evacuation model describing the egress in case of danger is considered. Therefore we show how to couple the spreading of some gaseous hazardous material to the underlying evacuation model, which is based on continuous network flows.

We use continuous network flows as we want to consider regional evacuation. Therefore we like to model the evacuees as a homogeneous group and do not take individual behavior into account. Thus we are going to make use of a macroscopic model. We use partial differential equations to model the transport on the arcs of the network and make use of some linearity assumptions on the flow function to be able to discretize the continuous model in a straightforward way. Additionally, for the correct formulation of the problem using partial differential equations it is necessary to define coupling conditions at nodes ensuring the conservation of mass. For instance, this is done in traffic flow [2,6] or supply chain modelling [4,3]. Especially the former are close to evacuation modelling and thus many ideas can be applied here, too.

We are able to show that the continuous network flow model we are using can be discretized as a discrete dynamic network flow problem. Here we have to mention that the ability to use discrete dynamic network flows as discretization for our continuous model strongly relies on the linearity assumptions on the flow function. But because of this special discretization we are able to state an efficient algorithm always leading to the global optimum, where optimality can thereby be understood with respect to two different measures: fastest egress and safest evacuation.

On the one hand fastest egress is a suitable objective function, since the zone of danger should be cleared in the shortest possible time to avoid the exposure of the evacuees to the hazardous material by leading them away from its source as fast as possible. This objective, also known as the quickest flow problem, has been widely studied for discrete dynamic network flows for example by Burkhard et al. [1] and Hamacher et al. [5], where the later has also dealt with time-dependent capacities, enabling models with temporally failure of arcs. Flow and load dependent travel times, reflecting the slow-down of evacuees due to congestion of arcs are considered by Köhler et al.[7,8]. Since we discretize our continuous network model in such a way that we can reformulate it as a discrete dynamic network flow model we can make use of the techniques mentioned above and are therefore able to state an efficient algorithm.

On the other hand we consider safest evacuation as an objective. This means that we take the spreading of the hazardous material into account when planning the evacuation. As this spreading is not necessarily uniformly distributed around the source of the hazard this objective yields different

solutions than the one discussed before.

The spreading of the hazardous material is described using a linear advection-diffusion equation since we like to focus on the mapping of the hazard on the network in this first approach as a more realistic propagation model may be included in a later step. The mapping of the hazardous material onto the network is then done by introducing a special cost function representing the level of hazard to which the evacuees are exposed. These costs are - in contrast to the travel times considered in the case of fastest egress - time-dependent. To solve the coupled model for safest evacuation we use again the discretization as a dynamic network flow problem ensuring the finding of a global optimum by using slightly other algorithms than for fastest egress.

REFERENCES

- [1] R.E. Burkard, K. Dlaska, and B. Klinz, *The quickest flow problem*, *Methods and Models of Operations Research*, 37 (1993), 31-58.
- [2] G.M. Coclite, M. Garavello, and B. Piccoli, *Traffic flow on a road network*, *SIAM Journal on Mathematical Analysis*, 36 (2005), 1862-1886.
- [3] C. D'Apice, S. Göttlich, M. Herty, and B. Piccoli, *Modeling, Simulation and Optimization of Supply Chains: A Continuous Approach*, *SIAM book series on Mathematical Modeling and Computation*, 2010.
- [4] S. Göttlich, M. Herty, and A. Klar, *Network models for supply chains*, *Communications in Mathematical Sciences*, 3 (2005), 545-559.
- [5] H.W. Hamacher and S.A. Tjandra, *Earliest arrival flows with time dependent capacity for solving evacuation problems*, in „Pedestrian and Evacuation Dynamics“ (eds. M. Schreckenberger and S.D. Sharma), Springer, Berlin, (2002), 267-276.
- [6] M. Herty and A. Klar, *Modeling, simulation, and optimization of traffic flow networks*, *SIAM Journal on Scientific Computing*, 25 (2003), 1066-1087.
- [7] E. Köhler, K. Langkau, and M. Skutella, *Time-expanded graphs for flow-dependent transit times*, *Lecture Notes in Computer Science*, 2461 (2002), 599-611.
- [8] E. Köhler and M. Skutella, *Flows over time with load-dependent transit times*, *SIAM Journal on Optimization*, 15 (2005), 1185-1202.

Minimizing the costs of evacuation paths by decomposing network flows

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Dynamic network flow models are a useful tool to calculate macroscopic evacuation plans for large scale regional evacuation. In such models every road is represented by an undirected edge in a network where the nodes are the junctions between roads. To every edge a maximal inflow capacity is assigned as well as a time needed to travel on the edge from start to end.

Over the years many models and algorithms have been developed to contribute to various facets of large scale routing and evacuation problems over time. This includes the optimization of total evacuation time, earliest arrival of evacuees and maximum throughput [1]. The models can also be extended by introducing additional cost functions on the edges for example to model a scenario where an evacuation happens in the presence of a toxic cloud. In such scenarios not only the evacuation time lies in the focus of the optimization but also the costs of the chosen evacuation plan. In the above example this corresponds to minimizing the exposure to the toxin during the evacuation process.

The solution of the network flow problems is naturally a flow on a network. However to decide where the evacuees should be sent a decomposition of this flow into evacuation paths is required. While it is straight forward to find an arbitrary decomposition of a flow this decomposition might not be unique. In addition not every decomposition will be equally good from a practical point of view. In fact the choice of a specific decomposition might have a tremendous effect on the quality of the solution. For example in the above scenario where the evacuation takes place in the presence of a toxic cloud a flow minimizing the total exposure of the evacuees to the hazard might have different decompositions. In one of them every person might be exposed to nearly the same amount, while in another decomposition some evacuees are exposed to an unacceptable high degree while other are not exposed at all. Note that those two solutions are equivalent in terms of the total exposure to the toxin but are obviously very different in quality.

The question considered here is how an optimal decomposition of a given flow with respect to some cost function can be found. This is a problem that has been addressed very rarely in literature but still is very crucial for evacuation planning. It has been shown that the problem is NP-hard [2] and hence it cannot be expected to find algorithms that solve the problem in polynomial time. Never the less an integer program is presented which can be used to compute optimal decompositions of small instances. For larger instances however both the number of constraints in the program as well as the runtime increase to a point where it is not longer efficient to use this approach. For this reason also an easy to implement approximation algorithm is presented which is based on a greedy strategy. This approximation algorithm can also be used for large scale networks but might not return the best solution possible. The quality of those solutions is analyzed and compared to the optimal solutions.

Obviously the best solution of the decomposition problem is a fair one where all paths have the same costs. However such a solution does not necessarily exist for the flow we have chosen. In fact it is possible to construct scenarios where it is only possible to find decompositions that have high costs on some paths and low costs on others. So starting from an arbitrary network the quality of a decomposition not only depends on the way a given flow is decomposed but also on the flow itself. It seems reasonable for the problem given to choose a flow that minimizes the total cost but there is no guaranty that this is the flow that has the best decomposition. Solving the more general problem starting from an arbitrary network is even harder than the problem considered here, since finding a decomposition of a given flow arises as a natural sub problem of the total problem. However it can be studied how the structure of the flow that is decomposed as well as the costs of the edges used by this flow affect the quality of the approximation algorithm as well as the lower and upper bounds of the optimal solution. This knowledge then might be used to construct a good starting flow for which the decomposition is calculated.

REFERENCES

- [1] H. W. Hamacher and S. A. Tjandra. *Mathematica modelling of evacuation problems: A state of the art. Berichte des Fraunhofer ITWM, 24:1–38, 2001*
- [2] Y. Hendel and W. Kubiak. *Decomposition of flow into paths to minimize their length. Available online at <http://sites.google.com/site/yannhendel/Decomposition.pdf?attredirects=0>.*

Modelling time duration of planned and unplanned store visits in a multi-agent simulation of pedestrian activity in city centres

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Agent-based modelling is a computational methodology that allows us to create, analyze, and experiment with artificial worlds populated by agents. A specific research area is micro-scale agent-based modelling that can be used for the simulation of pedestrian movement for low and high density scenarios and for the effect of changes in the environment. Such models can also be used for pedestrian dynamics in city centres to show the design effects in the shopping environment. Therefore, a multi-agent model to simulate pedestrian dynamic destination, route and scheduling behaviour is under development, where the simulation of movement patterns is embedded in a more comprehensive model of activity travel behaviour.

Representation is a main issue in simulating pedestrian dynamics. One can distinguish the representation of the pedestrian environment and the representation of pedestrians. In the domain of a city centre, representation of a pedestrian environment includes the geometry of the shopping environment such as stores and streets, the network as a cellular grid, and pedestrian objects. Pedestrian representation includes socioeconomic characteristics, speed, goals, familiarity with the environment, and activity agenda. It is assumed that pedestrians perceive their environment and that they are supposed to carry out a set of activities. For completing an activity, pedestrians spend time in stores. As a consequence, time duration influences their movement behaviour over the network.

Although a 3D presentation of pedestrians and the pedestrian environment for the simulation of pedestrian movement is the ultimate goal, it is nevertheless meaningful to test the underlying principles in an appropriate 2D representation of pedestrians and their environment. NetLogo can be used a simulation toolkit because it is a suitable simulation framework that supports modelling, simulation and experimentation. It also offers skeletons of agents and their environment, and interoperability (e.g. GIS). We will use shape-file information of the environment and network structure for visualizing the 2D environment and NetLogo for the actual simulation. For populating pedestrian agents in the environment and for attaching activity agendas to pedestrian agents, a Monte Carlo simulation is used which implies that the behaviour of each pedestrian agent is simulated by a series of draws of random numbers from successive probability distributions. The probability distributions are based on real data collections, such as time spent in a store, attaching inner lane or outer lane as an entry point and pedestrian characteristics (age, gender, etc.).

The main subject of this paper is to introduce the implication of time duration of planned and unplanned store visits within a simulation framework for pedestrian movement simulation. This framework involves an agent-based model that provides an activity agenda for pedestrian agents that guides their shopping behaviour in terms of destination and time spent in shopping areas. In order to

implement the activity agenda, pedestrian agents need to successively visit a set of stores and move over the network. It is assumed that pedestrian agents' behaviour is driven by a series of decision heuristics. Agents need to decide which stores to choose, in what order and which route to take, subject to time and institutional constraints. It is assumed that pedestrian agents are in different motivational states. They may at every point during the trip have general interests in conducting particular activities, without having decided on the specific store to visit, but they may also be in a more goal-directed motivational state in which case they have already decided which store to visit. To define pedestrian agents' motivational states, the categorization goal-oriented, leisure shopping, and no specific intention was made for their visit. The motivational states are of influence on the impulse and non-impulse store choice processes and therefore on the planned and unplanned visits to a store. All these aspects affect pedestrian agents' time duration in visiting stores. Pedestrian agents move over a street network and are part of a pedestrian flow in this street network. However pedestrian agents can be temporarily removed from the pedestrian flow by visiting a store and participating again in the pedestrian flow after visiting that store. In that case, the time spent by a pedestrian agent in a store is relevant. For the simulation run this time duration is determined by a Monte Carlo simulation. The findings from the collected data of the duration of a visit to a store indicate that this time duration meets the Weibull distribution, and that this duration also depends of the store category as well as the priority of the store.

This paper presents the findings of the implication of time duration of a visit to a store within a simulation framework for pedestrian movement simulation and the dependencies of this time duration with planned and unplanned visits to a store.

Empirical relations for bidirectional pedestrian stream in a corridor

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In recent years, extensive studies on uni- and bidirectional pedestrian flow in corridor have been done empirically and numerically. However, discrepancies exist among previous studies and there is no consensus about the origin of these discrepancies. Even for the fundamental diagram, the basic relation between density, velocity and flow rate, obvious differences can be observed especially for density $\rho > 2.0 \text{ m}^{-2}$ while comparing fundamental diagrams from different studies. Moreover there is no consensus whether the fundamental diagrams of uni- and bidirectional flows are different or not? Predtechenskii and Milinksii [1] and Weidmann [2] neglected the differences in accordance with Fruin, who states that the fundamental diagrams of multi- and uni-directional flow differ only slightly [3]. While Helbing et al. [4] concluded that counterflows at bottlenecks are significantly more efficient than unidirectional flows. Besides, the flow ratio of pedestrian in opposite streams is also an important topic in bidirectional stream. Navin and Wheeler [5] found a reduction of the flow in dependence of directional imbalances. Pushkarev et al. [6] and Lam et al. [7, 8] found that bidirectional flow is not substantially different from unidirectional flow as long as the densities of the opposite streams are not too different. However, Older et al. state that different ratios of flow in bidirectional stream do not show any significant effect on the walking speed [9].

To resolve these discrepancies series of experiments under laboratory conditions were carried out to study the characteristics of bidirectional pedestrian streams in a corridor. Two different kinds of bidirectional streams are created in our experiment: 1) pedestrian streams with stable separated lanes and 2) pedestrian streams with dynamic multi-lanes (with balanced and imbalanced flow ratios separately). The experiments were recorded by two cameras mounted on a rack at the ceiling of the hall. The pedestrian trajectories were automatically extracted from video recordings using the software PeTrack [10]. Given the advantage of small scatter and high resolution in time and space of the Voronoi method [11], we use it to calculate pedestrian characteristics including density, velocity and flow from these trajectories. It is shown that the fundamental diagram for various forms of bidirectional streams agree well and no large differences are found in observed density range. That is to say, the number and form of lanes in corridor doesn't have obvious on the pedestrian flow for density $\rho < 2.5 \text{ m}^{-2}$. By comparing the fundamental diagram between uni- and bidirectional stream, it is shown that the density-flow relationships agree well for the free flow state at density $\rho > 1.0 \text{ m}^{-2}$. However, the velocities for unidirectional flow are larger than that of bidirectional flow for $\rho > 1.0 \text{ m}^{-2}$. The maximum specific flow in unidirectional streams is significantly larger (about $0.5 \text{ 1/m}\cdot\text{s}$ higher) than that in bidirectional streams. In addition, the jamming transition from free flow state to jammed state, which is found in many theoretical models, was not observed in our experiment covering a density range up to $\rho = 3.5 \text{ m}^{-2}$.

REFERENCES

- [1] V. M. Predtechenskii and A. I. Milinskii, *Planning for Foot Traffic Flow in Buildings*. Amerind Publishing, New Delhi, 1978, translation of: *Proekttirovanie Zhdaniis Uchetom Organizatsii Dvizheniya Lyuddskikh Potokov*, Stroiizdat Publishers, Moscow, 1969
- [2] U. Weidmann, "Transporttechnik der Fussgänger," Institut für Verkehrsplanung, *Transporttechnik, Strassen und Eisenbahnbau*, ETH Zürich, ETH Zürich, Tech. Rep. Schriftenreihe des IVT Nr. 90, 1993, zweite, ergänzte Auflage.
- [3] J. J. Fruin, *Pedestrian Planning and Design*. Elevator World, New York, 1971
- [4] D. Helbing, L. Buzna, A. Johansson, and T. Werner, "Self-Organized Pedestrian Crowd Dynamics: Experiments, Simulations, and Design Solutions," *Transportation Science*, vol. 39, pp. 1–24, 2005
- [5] F. D. Navin and R. J. Wheeler, "Pedestrian flow characteristics," *Traffic Engineering*, vol. 39, pp. 31–36, 1969
- [6] B. Pushkarev and J. M. Zupan, "Capacity of Walkways," *Transportation Research Record*, vol. 538, pp. 1–15, 1975
- [7] W. H. K. Lam, J. Y. S. Lee, and C. Y. Cheung, "A study of the bi-directional pedestrian flow characteristics at Hong Kong signalized crosswalk facilities," *Transportation*, vol. 29, pp. 169–192, 2002
- [8] W. H. K. Lam, J. Y. S. Lee, K. S. Chan, and P. K. Goh, "A generalised function for modeling bi-directional flow effects on indoor walkways in Hong Kong," *Transportation Research Part A: Policy and Practice*, vol. 37, pp. 789–810, 2003
- [9] S. Older, "Movement of Pedestrians on Footways in Shopping Streets," *Traffic Engineering and Control*, vol. 10, pp. 160–163, 1968
- [10] M. Boltes, A. Seyfried, B. Steffen, and A. Schadschneider, "Automatic Extraction of Pedestrian Trajectories from Video Recordings," in *Pedestrian and Evacuation Dynamics 2008*, W. W. F. Klingsch, C. Rogsch, A. Schadschneider, and M. Schreckenberg, Eds. Springer-Verlag Berlin Heidelberg, 2010, pp. 43–54
- [11] J. Zhang, W. Klingsch, A. Schadschneider, and A. Seyfried, "Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions," *Journal of Statistical Mechanics: Theory and Experiment*, vol. P06004, 2011

HERMES – An evacuation assistant for large arenas

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The trend towards large multifunctional buildings as well as the dimensions of public events makes new demands on the quality of security concepts. In case of emergency, all the attendees must be able to evacuate the danger area rapidly. Although this is generally ensured by the application of building regulations, it can result in a dangerous crush and long queues in case of overcrowding or if some of the emergency exits are blocked. In recent years we have seen an increasing number of crowd disasters with many injured persons, e. g. Love Parade in Duisburg (Germany).

In order to prevent such critical situations optimal crowd management needs accurate and up-to-date information about the current state in the arena. In the three-year research project HERMES – funded by the German Federal Ministry of Education and Research (BMBF) – we have developed an evacuation assistant. In the project a total of 13 partners have worked together. In addition to the research institutions and business enterprises the end users (police, fire fighters and security guards) were involved in the exploration of the evacuation assistant. The aim of the assistant is to incorporate the current state of the building, but also the number and distribution of persons present in the simulation. So for the first time it is possible to obtain real-time simulation results based on the actual risk situation.

The ESPRIT Arena in Düsseldorf (Germany) provided a venue for implementing the evacuation assistant. The example of this multifunctional area with a capacity of more than 60,000 spectators showed how crowds of people at big events can be guided so that optimal use can be made of the emergency exits. The aim of the HERMES Project is to produce a real-time simulation for a reliable forecast of the evacuation behavior. The task forces will receive important information, but the decision on the optimal strategy will be taken in each case by the forces themselves.

The project HERMES consists of several components:

- a) Safety and security management system
- b) Video-based person counting
- c) Real-time simulation core
- d) Communication module

The safety and security management system provides information about the condition of the building. So we know if escape routes are smoky or whether parts of the building were closed e. g. because of a bomb threat. The video-based person counting provides reliable data on the number of people who are currently in the parts of the building. Data privacy is taken very seriously here: we do not store video images, but only the count data will be passed. Based on these data, the system operator can now define

a scenario that will be calculated from the simulation tools.

In our project HERMES, three different models are combined to obtain reliable predictions from the simulations and achieve an optimal performance. One approach relies on a macroscopic model allowing a routing recommendation [1]. Additionally we use two microscopic models (floor field cellular automaton model [2] and the generalized centrifugal force model [3]) which provide rather detailed predictions about the development of an evacuation. To increase the reliability of the forecast large-scale experiments have been performed in the laboratory and the arena itself. These data are complemented by field studies. The results from these experiments have been used to calibrate the models in order to make quantitative predictions.

Essential for the practicality of the evacuation assistant is the treatment of the resulting data. The front end of the system is therefore a communication module. The type of visualization has been jointly developed and tested with the end users. With a traffic light system (red, yellow, green) it can be determined on a first glance whether the allowable number of occupants is exceeded in some areas of the building. Based on the micro-simulation it is shown, where critical traffic jams will arise during the next 15 minutes. Due to these results the responsible team leaders have the opportunity to deploy their employees so that pedestrian traffic can be directed optimally.

In this contribution we will present an evacuation assistant for mass events providing results in real-time. The assistant is currently absolving a test phase in the facilities of the ESPRIT Arena in Düsseldorf. An overview of results and conclusions of the project HERMES will be presented.

REFERENCES

- [1] A. Schomborg, K. Nöckel and A. Seyfried. *Evacuation Assistance for a Sports Arena Using a Macroscopic Network Model*. In: R. Peacock, E. Kuligowski and J. Averill (ed.), *Pedestrian and Evacuation Dynamics 2010*, Springer, p. 389-398 (2011)
- [2] C. Burstedde, K. Klauck, A. Schadschneider, and J. Zittartz. *Simulation of pedestrian dynamics using a two-dimensional cellular automaton*. *Physica A*, 295:507525, 2001.
- [3] M. Chraibi, A. Seyfried, and A. Schadschneider. *Generalized centrifugal force model for pedestrian dynamics*. *Physical Review E*, 82:046111, 2010.

Analysis of flow-influencing factors in mouths of grandstands

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Since many years, football is one of the most popular sports in Germany. During the German Soccer League season, every week thousands of fans occupy the grandstands of football stadiums to watch and support their favorite team. The large number of people ensures a great atmosphere, but also involves risks concerning safety aspects. In hazardous situation, a quick evacuation can be necessary. People have to leave their seats and follow the evacuation routes to the mouth of the grandstand. The mouth itself, i.e. the connection to the exit, has a key function in the evacuation process, because different pedestrian streams merge. Our goal is to analyze movement of pedestrian streams quantitatively in grandstands of stadiums with special regard to the conduct to the mouth. Thus the design of the grandstand including the layout of paths and the mouth could be optimized regarding safety and economic aspects.

The german building code offers several requirements concerning the width and length of escape routes, but the geometry of the mouth isn't considered yet. Also for the merging of different pedestrian streams, insufficient information is available in the literature. Only Predtetschenskii and Milinskii [1], who present a macroscopic model to describe pedestrian movement quantitatively, give some information about the merging process. Incoming flows are added and the capacity of the foregoing corridor is checked. Thus, if the sum of the incoming flows exceeds the capacity, jamming will occur.

To improve the knowledgebase and the level of safety regarding an evacuation of places of assembly like a sports stadium, experiments under laboratory conditions were carried out in the ESPRIT arena in Düsseldorf within the HERMES project [2]. Overall eight runs with different setups (up to 300 persons) were performed in the grandstands to analyze the merging effect of two and three pedestrian streams, the influence of different densities (e.g. every second seat used) and obstacles like a closed door wing or security personnel. To proof the dependency of the incline of the grandstand on these parameters, the runs have been performed in the sub- and upper-rank (incline 27° and 33° resp.) of the ESPRIT arena. The experiments were recorded by two stereo cameras and precise pedestrian trajectories (± 50 mm) were extracted automatically from video recordings using the software PeTrack [3]. Thus a microscopic analysis of pedestrian characteristics including density, velocity and flow is feasible.

The results of the experiments show, that the incline of the grandstand has an influence on the pedestrian flow on the stairs, which lead to the mouth. Thus, the flow in the mouth is affected by the reduced incoming flow respectively. Maximum specific flow measured in the mouth of the upper-rank is $1.66 \text{ (m}\cdot\text{s)}^{-1}$ and in the sub-rank $1.83 \text{ (m}\cdot\text{s)}^{-1}$. That the incline influences the fundamental diagram for stairs is already documented in the SFPE Handbook [4] and by Frantzych [5, 6], but the influence on the flow in the mouth connected with the overall evacuation time, isn't considered yet. Our

experiments show, that the strategic positioning of the security personnel has a significant influence on the pedestrian flow in the sub-rank, but surprisingly only a minor influence on the flow in the upper-rank. Using the Voronoi method [7], we made topographical measurements in the mouth during stationary states. Highest density appears ($\rho \approx 3 \text{ m}^{-2}$) in the region where the incoming pedestrian streams merge.

REFERENCES

- [1] V. M. Predtechenskii and A. I. Milinskii, *Planning for Foot Traffic Flow in Buildings*. Amerind Publishing, New Dehli, 1978, translation of: *Proekttirovanie Zhdanii s Uchetom Organizatsii Dvizheniya Lyudskikh Potokov*, Stroizdat Publishers, Moscow, 1969.
- [2] “Hermes - investigation of an evacuation assistant for use in emergencies during large-scale public events,” <http://www.fz-juelich.de/jsc/hermes>, March 2011.
- [3] M. Boltes, A. Seyfried, B. Steffen, and A. Schadschneider, “Automatic Extraction of Pedestrian Trajectories from Video Recordings,” in *Pedestrian and Evacuation Dynamics 2008*, W. W. F. Klingsch, C. Rogsch, A. Schadschneider, and M. Schreckenberg, Eds. Springer-Verlag Berlin Heidelberg, 2010, pp. 43–54
- [4] P. J. DiNenno, *SFPE Handbook of Fire Protection Engineering*, 3rd ed. Quincy MA: National Fire Protection Association, 2002.
- [5] H. Frantzich, “A model for performance-based design of escape routes,” Department of Fire Safety Engineering, Lund Institute of Technology, Tech. Rep. 1011, 1994.
- [6] Frantzich, H., “Study of movement on stairs during evacuation using video analysing techniques,” Department of Fire Safety Engineering, Lund Institute of Technology, Tech. Rep., 1996.
- [7] J. Zhang, W. Klingsch, A. Schadschneider, and A. Seyfried, “Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions,” *Journal of Statistical Mechanics: Theory and Experiment*, vol. P06004, 2011

Poster exhibition

Unsorted list

Beril Sirmacek, Deutsches Zentrum für Luft- / Raumfahrt, Oberpfaffenhofen GERMANY
Understanding social behaviors of pedestrian crowds in airborne images based on a graph-cut and sub-graph matching based framework

Sven Hebben, TraffGo HT GmbH, Flensburg GERMANY
Evacuation analysis for venues: Systematical approach and comparison to evacuation trials

Konstantinos Kostas, Technological Educational Institute of Athens, Athens GREECE
Motions effect for crowd modeling aboard ships

Gabriel Wurzer, AIT Austrian Institute of Technology, Wien AUSTRIA
Early-stage egress simulation for process-driven buildings

Xiaolei Zou, Tongji University, Shanghai CHINA
Experimental study of the passengers' self-learning in spatial structure of urban mass transit stations with cognitive map

Douglas Samuelson, InfoLogix Inc., Annandale VA USA
Agent-based simulations of pedestrian movement for site security: U. S. Secret Service's current capabilities and next steps

Martin Lopusniak, Technical University of Košice, Košice SLOVAKIA
Comparison of simulation results with evacuation test and normative calculation

Daniel Weber, Universität Duisburg-Essen, Duisburg GERMANY
Merging of pedestrian queues: a mean field approach for CA models

Carlos Pretto, Federal University of Rio Grande do Sul, Porto Alegre BRAZIL
Simulation model for vehicle and pedestrian interaction considering road crossing activities

Characteristics of pedestrian trips in Indian cities

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Pedestrian is one of the most vital components of any transportation system. The pedestrian, by far, constitute the most vulnerable road user group comprising high proportion of road accident fatalities . In order to promote walking as a safe, healthy and sustainable form of transport and prioritising the needs of pedestrians in the urban environment it becomes necessary to manage its movement. In the inner city, this will include the identification of conflict points and the development of improved movement in the context of the emerging urban structure and urban framework while for outside the city core emphasis could be placed which facilitates on creating and promoting a safe pedestrian environment. Pedestrian and cycling policies in a developing country like India could even be more important today when cities are planning massive augmentation of public transport. Metro, bus rapid transit system and standard buses cannot work optimally if these are not supported with a good pedestrian network. Any attempt to improve the share of public transport will lead to correspondent increase in walking and roads will have to be planned with more walking space. The present paper is based on the evidence collated and analysed on the pedestrian trips characteristics across different sized cities in India.

The growth of urban population in India has been extremely rapid during the course of last century. While the total population of India has grown from 361m in 1961 to 1027m in 2001 the urban population has increased from 62m to 285 m in the same period. The percentage share of urban population has gone up from 17.3% in 1951 to 27.8% in 2001. The number of urban settlements too have gone up from 2845 in 1951 to 3969 in 2001. The share of Class-I cities (with population of one lakh and above) in the total urban population has increased from 44% to 68% during the above period. The concentration of population in the ,million plus' cities has been particularly striking. Their number has increased from 5 in 1951 and 35 in 2001. These 35 cities together had a population of 107.1 million in 2001, accounting for 37.7% of India's urban population. The average trip length tends to increase from 3.16 km in size I cities to 5.58km in size VI cities while the mechanized trip lengths increase from 4.04 km to 7.97 km respectively. The share of public transport trips increases from 18.8% in size I cities to 69.3 % in size VI cities.

In India the share of walk trips in cities generally vary between 20 to 30 % across varying city sizes. A higher share is observed in lower order cities which keeps declining as cities grow in size.

In terms of walk trips it is observed from an analysis of 30 cities of varying sizes that the walk trips share vary between 16 percent to 34 percent with an exception of 57% in hilly terrain cities less than 0.5 million population size. Generally the share of walk trips tend to decrease with increasing city size. It was also observed that small cities and particularly in hilly terrain exhibit a very high share of walk

trips on account of compact size, dense core, greater accessibility and lesser number of motorized vehicles making these cities immensely walkable. It was also observed that walk trips account for 21.5% share in business trips, 10.5% for service and 58% for education travel. Based on data pertaining to walkability in 30 cities it was observed that walking is predominant mode for urban poor. It is further seen that as the pedestrian environment continues to deteriorate the resident population is forced to accept hostile and unsafe walking conditions. The paper will also highlight the analysis of walk trips.

Understanding social behaviors of pedestrian crowds in airborne images based on a graph-cut and sub-graph matching based framework

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Automatic understanding of human behaviors became a very attractive topic, since these systems can provide crucial information to police departments or to crises management teams in order to prevent disasters or other unpleasant situations. Therefore, recently many researchers slid their focus into this topic. In the last decade, many studies have been proposed to detect and track people from ground camera images which are also known as close-range images. Most of these studies focused on detecting boundaries of large groups and extracting global attributes of them. Unfortunately, street these cameras have limited coverage area to monitor large outdoor events. In addition to that, in most of the cases, it is not possible to obtain close-range images or video streams in the place where an event occurs. Therefore, in order to understand behaviors of people in very big out-door events, the best way is to use airborne images which began to give more information to researchers with the development of sensor technology.

In our previous studies, we have proposed novel approaches to detect and track people from airborne images. In our first step, we have focused on detection of dense crowd boundaries from airborne images [1]. By implementing a self-parameter-adaptation module, we could also detect dense crowd boundaries in different scale input images such as high resolution satellite images [2]. In following study [3], we have extended the study and besides detecting dense crowd boundaries we could also detect locations of individual persons in sparse regions. Using registered airborne image sequences, we tracked detected individuals based on Kalman filtering process. With Butenuth et al. [4], we have worked on understanding human behaviors using motion trajectories of individuals. Although obtained results were promising, obtaining motion trajectories was not implemented as an automatic process. Therefore we can conclude that automatically understanding human behaviors is still an open and challenging problem. In order to bring an automatic solution to this problem, herein we propose a novel mathematical approach based on graph-cut and sub-graph matching processes. We start with generating a graph network for each frame of the input sequence by assuming detected person locations as nodes of the graph and the Euclidean distance between them as graph edges. Then we cut obtained graph into sub-graphs by checking their neighborhood node properties. For each obtained sub-graph we generate a feature vector again using graph properties such as; mean number of neighbors for each node, sizes of sub-graph, velocity of sub-graph in previous frames, amount of node number change comparing with the previous frame. After generating the descriptor feature vector for each sub-graph, we compare them with the descriptor feature vectors which are previously generated and stored in a database for sample sequences like meeting groups, diverging groups, queuing group etc. We apply our mathematical analysis on toy sequences. Additionally, we also test our algorithm on an airborne image sequence. Obtained automatic results indicate possible usage of the proposed approach on real-scene sequences.

REFERENCES

- [1] B. Sirmacek, P. Reinartz, „Automatic Crowd Analysis from Airborne Images“, 5th International Conference on Recent Advances in Space Technologies RAST 2011, Istanbul, Turkey, June 2011.
- [2] B. Sirmacek, P. Reinartz, „Automatic crowd analysis from very high resolution satellite images“, Proceedings of Photogrammetry and Image Analysis Conference (PIA'11), Munich, Germany, October 2011.
- [3] B. Sirmacek, P. Reinartz, „Kalman Filter Based Feature Analysis for Tracking People from Airborne Images“, ISPRS Workshop High-Resolution Earth Imaging for Geospatial Information, Hannover, Germany, June 2011.
- [4] M. Butenuth, F. Burkert, A. Kneidl, A. Borrmann, F. Schmidt, S. Hinz, B. Sirmacek, D. Hartmann, „Integrating pedestrian simulation, tracking and event detection for crowd analysis“, Proceedings of the 1st IEEE ICCV Workshop on Modeling, Simulation and Visual Analysis of Large Crowds, Barcelona, Spain, November 2011.

Evacuation analysis for venues: Systematical approach and comparison to evacuation trials

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SCOPE OF WORK

This paper illustrates the systematical approach for evacuation simulations and the comparison of the results to real world data for calibration and validation.

Evacuation Analyses are a tool used in Fire Safety Science to assess building layouts and venue locations. One area of application is to optimize person flows. Another one is to assess deviations from prescriptive guidelines, e.g. concerning the dimensioning of escape routes. For certain types of buildings, prescriptive guidelines cannot be applied directly. This might be the case for architecturally demanding buildings, for sports stadia, etc. In that context, problems of different procedures or definitions of acceptance criteria might arise. The reason is that prescriptive guidelines for buildings in Germany and Austria do not provide any criteria concerning evacuation simulations, evacuation times or maximum densities for escape routes.

In Germany there are two projects to develop certain boundary conditions to standardize the procedure of evacuation analyses. One of these is the RiMEA project (Richtlinie für Mikroskopische Entfluchtungsanalysen - translated: Guideline for Microscopic Evacuation Analyses), which defines the required aspects to consider while preparing and analyzing a building project. The second one is chapter 9 of the vfdb Leitfaden Ingenieurmethoden im Brandschutz (vfdb Guideline for engineering methods in fire safety). This guidelines specifies some basic parameters for the input of evacuation calculations.

In this paper, two examples of application for that procedure (i.e. analysis according to RiMEA in combination with vfdb) are shown. One is a entertainment show in the Graz city hall in Austria, the other one is a TV studio in Germany.

EVACUATION TRAILS

The first of the evacuation exercises was conducted in Graz in August 2010. This exercise was prepared by the fire Brigade of Graz in the City Hall. The venue in which the exercise took place was the upper floor of the exhibition hall A. The room had a capacity of about 1250 persons, which were placed in seat rows in front of a stage. The evacuation should take place in the evening during a program of different presentations and a political cabaret. The persons participating were informed about the evacuation exercise in the beginning. The point in time, in which the evacuation was started, had been concealed from the persons present.

The hazard scenario was characterized by a bomb threat with a following ignition in the entrance hall. To create a more realistic situation, fog machines and sound systems were used to support the scenario. Due to this scenario, the main entry of hall was closed. The persons were instructed to leave the building via the emergency exits. The evacuation was assisted by marshals, which were placed in the room during the bomb threat.

The second exercise in a TV Studio in Cologne was conducted twice. In both exercises about 450 persons were seated on grandstands. They were instructed to leave the studio via the emergency exits shortly after the recording of a TV show. The exercises were performed with different conditions. The first one was announced, the second one was unannounced.

SIMULATION

The model used to perform the evacuation analyses is PedGo. The basis of this simulation model is a multi agent model, which is based on a cellular automaton. The agents are represented individually and their characteristics are defined by individual parameters. Those are walking speed, reaction time, dawdle, sway, inertia, and group behaviours. The parameters are chosen according to the specifications given in RiMEA. The geometry of the buildings, which are defined by CAD drawings, are divided into a cellular grid with a cell size of 0.4 x 0.4 m. The results of the simulations shown and compared to the results of the evacuation trials for calibration and validation purposes.

Motions effect for crowd modeling aboard ships

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Virtual Environment for Life On Ships (VELOS) is a multi-user Virtual Reality (VR) system that supports designers to assess (early in the design process) passenger and crew activities on a ship for both normal and hectic conditions of operations and to improve the ship design accordingly [1]. The crowd modeling component of VELOS is build upon the steering behaviors technology and related enhancements that allow for consideration of passenger grouping and crew assistance behavior effects in ship evacuation simulations [2].

Furthermore, VELOS provides communication interfaces enabling data import from computational packages, including sea-keeping and fire events modeling software. Pre-computed ship-motion history has been used in VELOS as a simple means for considering the effect of ship motion on simulated passengers' movement via the introduction of the inclination steering behavior. Inclination behavior resembles in definition and effect the influence of a gravity field that would hinder agent motion accordingly. The aforementioned approach is a simple kinematic model that does not account for the dynamic nature of the phenomenon thus ignoring motion accelerations. Ship-motion accelerations, however, are critical to the assessment of a person's balancing and/or sliding aboard ships and consequently to its capability of performing an assigned task. In this work, we are focusing on the exploitation of pre-computed ship motion accelerations, readily available by the connected sea-keeping computational packages. Based on the works by Graham [3] and Crossland et al [4] we investigate the usage of Motion-Induced Interruptions (MIIs) and tipping coefficients in modeling the effect of ship-motion accelerations aboard.

Specifically, in accordance to the calculated MII risk level, we modify steering behaviors' weighting and/or behavior parameters to address the corresponding possibility of a motion interruption and degradation of assigned tasks' effectiveness. The assumption employed here is that a ship-motion-interrupted simple task, such as walking from point A to point B with MII incidents, could equivalently be modeled by a modification of the steering behaviors blending that would lead to similar task effectiveness. This becomes more evident if we consider the following basic steering behaviors: Obstacle Avoidance, Wander and Separation. As persons are faced with sea states that lead to high possibilities of MII incidents their obstacle avoidance and separation capabilities are degraded, while the wandering component receives a more significant contribution. This modeling approach is effective within certain bounds: a lower threshold that signifies the beginning of non-negligible ship motion effects, and an upper threshold, beyond which task completion is impossible.

Our approach is finally demonstrated and analyzed for two test-cases: A) a normal condition scenario where typical passenger and crew movements are simulated and B) a hectic condition scenario where

an evacuation simulation for a ship's aft vertical zone is performed. Both scenarios are examined with and without consideration of the ship motions effect on simulated passenger and crew movement.

REFERENCES

- [1] A.I. Ginnis, K.V. Kostas, C.G. Politis, & P.D. Kaklis, 2010, "VELOS: A VR Platform for Ship-Evacuation Analysis", *JCAD special issue on Computer Aided Ship Design*, volume 42, issue 11, p.1045-1058.
- [2] K.V. Kostas, A.A-I Ginnis, C.G. Politis & P.D. Kaklis, 2011, "Use of VELOS platform for modelling and accessing crew assistance and passenger grouping in ship-evacuation analysis" in *IMAM 2011 Genoa proceedings : "Sustainable Maritime Transportation and Exploitation of Sea Resources"*, Eds E. Rizzuto, C. Guedes Soares, vol. 2, pp. 729-736.
- [3] R. Graham, 1990, "Motion-Induced Interruptions as Ship Operability Criteria", *Journal of Naval Engineers*, vol. 102, issue 2, pp. 65-71.
- [4] P. Crossland, M.J. Evans, D. Girst, M. Lowten, H. Jones and R.S. Bridger, 2007, "Motion-induced interruptions aboard ship: Model development and application to ship design", *Journal of Occupational Ergonomics*, vol. 7, pp. 183-199.

Early-stage egress simulation for process-driven buildings

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ABSTRACT

Many complex buildings such as hospitals, airports and industrial facilities are process-driven, meaning that their design is conceived around the daily work routines of the staff, usually captured using business processes (e.g. by using flowcharts or Business Process Modeling Notation). The main idea and contribution of our approach is to leverage such a static process model in order to facilitate a dynamic egress simulation. In detail, we perform a process simulation until a specified time t is reached. As result, we get the typical location of the working staff as well as occupancy of all areas of the building, which we then feed into an agent-based egress simulation. As result, we can obtain the evacuation performance at time t under consideration of the building's process model, i.e. different usage scenarios throughout the day. This hybrid approach between process simulation and pedestrian simulation is especially suited for early stages of building design, when different spatial configurations and process variants are under consideration. In this context, the approach is just one part of many lines of architectural reasoning, covering foremost the problem of reachability and adjacency by means of pedestrian simulation.

ELABORATION

The planning of process-driven buildings is occupied foremost with the production of a spatial design that facilitates the daily work routines of the building users. Especially in the early phases of the design project, architects and organization planners work in close cooperation to achieve this goal:

- Organization planners define the operational model of the organization, which takes the form of a hierarchy of business processes (processes and sub-processes), an organizational schema containing the responsibilities for each process (i.e. process roles), and, ultimately, a definition of staffing needs arising out of the process model.
- Architects define a spatial configuration that satisfies the organizational requirements, most prominently: the business processes. In this context, multiple variants of a preliminary design (also called architectural schema) are being evaluated, the key criterion being the adjacency of areas which exhibit a high degree of cooperation (as described by the process model).

In previous work[1], process simulation has been used to superimpose business processes over the preliminary design, in order to constrain the spatial concept so that it fulfills the process model and at the same time visualize work routines of the staff. This paper extends on these concepts, by introducing a (dynamic) egress simulation that is based on the state of the aforementioned (static) process simulation at a time t . More specifically, we:

1. The state of the process simulation at time t gives the usage of each space.
2. An egress simulation takes this usage and computes the pedestrian flow to the nearest exits.
3. The recorded density and evacuation times can then be visualized and subsequently used to get an insight into bottlenecks occurring because of the spatial arrangement and expected occupation of the building at time t , at quite an early stage in the project.

SUMMARY

We propose a hybrid approach linking static process simulation to dynamic egress simulation, in order to visualize bottlenecks and reachability problems for process-driven buildings. In contrast to existing egress simulations, our efforts are targeted at early stages of design and act as qualitative means rather than giving quantitative statements. The choice of process simulation and pedestrian algorithm is free (the authors use an own process simulation linked to a Blue-Adler[2] model).

REFERENCES

[1] Wurzer, 2010: „Schematic Systems -Constraining Functions Through Processes (and Vice Versa)“; In *International Journal of Architectural Computing*, Vol. 08 (2010).

[2] Blue and Adler, 2000: „Cellular automata model of emergent collaborative bidirectional pedestrian dynamics“; In *Proceedings of Artificial Life VII, Portland*.

Experimental study of the passengers' self-learning in spatial structure of urban mass transit stations with cognitive map

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Path finding, routing and path planning are important research fields in pedestrian crowd simulation. The existing algorithms are mostly based on the thoughts of optimization and prefer the paths with shorter distance, less time, and lower cost. So it is hard to reflect the real traffic assignment and moving paths of the crowd with a single path algorithm. And many crowd simulation cases conducted overly optimistic results in crowd control and evacuation because they ignored the variations in individuals' preference and familiarity to the environment.

In this paper, passengers of urban mass transit station are studied on their changing in spatial cognition and path preference over time. And a simulation framework is defined based on a self-learning process and the diversity of path finding and routing of the individuals to make the crowd simulation more realistic.

THE USE OF COGNITIVE MAPS

Cognitive map is generated by the experiences of people. It is a tool for people to collect, organize, store and process the spatial information. In this paper, it is used in the experiments and analysis. It stores the information of spatial structure of the station, the layout of service equipment, the service procedures, assignment of passengers and used paths for each examinee constantly.

RESEARCH METHODES AND PROCESS

The experiments were conducted at the interchange station of Peoples' square and a common station of metro line No.10 in Shanghai. 100 freshman students who were new to the stations were selected as passengers. They were divided into four groups to repeat 10 times the procedures of alighting, departure and interchanging at the 2 stations and drew their cognitive maps after each experience. And the groups were required to repeat the procedures with different time interval. In this way, the variations in size and function of the station, in trip purpose of passengers, and in practice frequency were considered. The learning curve in different experiment conditions could be drew and compared.

CONCLUSION AND INSPIRATION

I. The constraints for path finding and routing

According to the experiment and survey, the main constraints for path finding and routing are the distance, the passenger service level, the density of the crowd, and the comfort level of walking along the path. These constraints compose the preference of the passengers in path finding and routing.

II. The spatial learning curve and changing from path finding to routing

The constraints above become clearer as the individuals practice and learn more about the station.

The cognitive map becomes more complete and the path finding turns to routing and the choice of the individual becomes more rational.

III. The routing and assignment of the crowd

At any time, the crowd contains individuals with different cognitive maps of the station. The variations in preference and familiarity level make a diversified routing of the individuals and assignment of the crowd.

IV. The Simulation Framework Based on Cognitive Map and Self-learning Process

The paper proposes a crowd simulation framework for urban mass transit station. The framework contains a library of both path finding and routing models that suit for different preferences and a set of cognitive maps for individuals in different self-learning stage. It becomes possible to construct more realistic simulation environments for representing the movement of passenger crowd in stations for operation optimization and alternative evaluation for safety and efficiency purpose.

REFERENCES

[1] Peng Gao, Ruihua Xu and Xiaolei Zou. *3-tier Architecture for Pedestrian Agent in Crowd Simulation. Pedestrian Evacuation Dynamics 2008. Springer, 2010:585-596.*

[2] WAN Gang, GAO Jun, LIU Ying-zhen. *Research on Cognitive Map Formation Based on Reading Experiments. Journal of Remote Sensing. Vo.12, No.2 Mar., 2008. P339-346.*

Agent-based simulations of pedestrian movement for site security: U. S. Secret Service's current capabilities and next steps

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For the U. S. Secret Service, we assessed the state of current capabilities in agent-based simulations of mass egress and evacuation. We consider how to address some of the most significant challenges at present in developing and using such models. We focus in particular on behaviors likely to occur in crisis egress situations and the effects those behaviors are likely to have on managing egress. Of these, the most significant are:

- Realistic variation in speeds of movement, including the effect of different mixes of demographic characteristics of people in the crowd.
- Variations in the effect of the situation: obscured sight lines, interference with vision, signage, apparent urgency.
- Group movements and the consequent delays.
- Counter-flows in some situations, such as parents going back to assist children.
- Movement by disabled people and others trying to assist them.
- Effects of direction and instruction and of various ways, both at the time in advance, of conveying this information.
- Effects of known or suspected secondary hazards, such as toxic plumes.
- Effects of placement of resources and command posts.
- Contra-flow, the ingress of emergency responders.
- Pre-positioning resources, such as firefighting equipment, medical aid stations and personnel.
- Effects of alternative provisions for medical care on-site or keyed to transportation off-site.

The U. S. Secret Service addressed the continuing issue of speed of execution versus fidelity and detail by dividing its efforts: a large-scale planning model (Evacuation Planning Tool, or EPT) and a smaller-scale, more realistic Site Security Planning Tool (SSPT) for training protective personnel. SSPT is video-game based and highly adaptable, well suited to its purpose. The Secret Service also explored federating (linking) these models with the U. S. Naval Research Laboratory's CT-Analyst model of toxic plume dispersion.

Pure modeling issues still pose significant challenges. The "Holy Grail" of modeling mass egress is to have a single user interface through which one can access realistic large-scale models of venue-scale and neighborhood-scale events, running in near real time, for exercises, planning, and assessment of alternative courses of action; smaller, highly-realistic real-time models for use in training security personnel, and situation awareness real-time presentations for use in actual incident management. This structure would make it possible for incident managers to train and plan with the same depictions they then see in actual occurrences. This seamlessly integrated capability is still several years away at best,

however, so some current trade-offs and advancements are indicated:

- Faster overview models of incidents, possibly by compromising detail and realism in depiction.
- Larger and more comprehensive models of site security for training.
- Faster, more realistic smaller-scale models of site security, running like video games, for specific training exercises.
- More attention to eventual connections and docking among models, including the design considerations involved in making scale, nomenclature and units of measurement compatible.
- Making digital output as well as graphics standard, so that the next model can use the digital version of the previous model's computations as input for its own calculations.
- More attention to ease of modification of models.
- Easier and more widespread access by local law enforcement and event security personnel.

The rapid proliferation of efforts in this area and the accelerating advance of the relevant technology makes flexibility of design critical if models currently under development are to remain useful long enough for incident managers to learn, train, analyze and work with them. Secret Service's recent and current projects represent a substantial step forward in addressing this complicated and vital issue.

Comparison of simulation results with evacuation test and normative calculation

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Design of escape routes is carried out according to a standard procedure using simple mathematical formulas. This procedure is very limited for both an architect and an owner of a building. According to this procedure is not possible to carry out any depth analysis of an evacuation. The result is a simple time of a people evacuation from a building. The use of evacuation models gives a user an ability to carry out a comprehensive analysis of a people evacuation from a building. The result is not only the time of evacuation, but also a comprehensive quantitative and qualitative analysis of a people evacuation. Verification of an evacuation model is an essential requirement for its use in the legislative framework of the Slovak republic. Paper presents a verification of the reliability of the evacuation model buildingExodus according to the evacuation test results as well as against the results from the standard calculation procedure.

The basic method for work is the computational simulation using the evacuation model buildingExodus. As the normative calculation method was used the calculation according to STN 920102 - Evacuation of people. The results of calculations were mutual compared. Evacuation test was conducted in an university environment. In the test was created situation as to evacuate students from classes to the outside. A total of six runs were performed. During the test were recorded evacuation times as well as different physical movement characteristics of test participants. Data obtained were then used to compare simulation results with the results of the evacuation test. Obtained evacuation times from the simulation, normative calculation and evacuation tests was compared in five series, which are labeled S1 to S5. Each series contains a set of results, the extent of which depends on a number of variations in input data calculations. They were compared to runs 1 to 4 with the simulation - series S1. Series S2 is a comparison of runs 5 and 6 with the simulation test. Comparison of the results from normative calculation with the results from evacuation test was also performed separately for runs 1 to 4 - series S3 and runs 5, 6 - series S4. Mutual comparison of the simulation and the normative calculation is a series S5. Physical characteristics of participants were accurately entered into the simulation and calculation according to information obtained by questionnaire. Population and population panels have been established in accordance with the test groups during the evacuation test. The geometry of space was created with the CAD import. Reaction time in each simulation was equal to zero. No other behavioral modifications were made.

The achieved results confirm that the evacuation model can be classified as reliable for use in the legislative framework of the Slovak republic. When comparing the results of the evacuation test and the simulation was consensus in the overall evacuation time from 85 to 95%. The largest differences and the smallest compliance of the results were on evacuation routs from each room. In this case it was a short time period and short distance for people to escape. Based on the data may draw the

necessary conclusions on the use of evacuation model for a design and assessment of escape routes in the legislative framework of the Slovak republic. For wider use of evacuation models must be created conditions and evaluation criteria.

Merging of pedestrian queues: a mean field approach for CA models

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Merging processes of particle streams are a crucial aspect in the modeling of various transport phenomena. We study analytically and numerically the merging of separate pedestrian queues from two narrow corridors into a single-lane stream. Pedestrians are treated as moving particles on a lattice with hard core exclusion and parallel lattice dynamics. This corresponds to the floor field cellular automata models (3) of pedestrian dynamics where space is discretized in quadratic cells. Each cell can be either empty or occupied by exactly one pedestrian. Due to the parallel update scheme conflicts may arise in the intersection area when two pedestrians try to enter the same cell.

To solve these conflicts we use an additional friction parameter which was introduced by Kirchner et al.(1). By varying the friction parameter the merging process of pedestrians from different streams can be varied from “cooperative” to “competitive”. Contrary to previous work (2), we consider a Moore neighborhood at the junction such that pedestrians from one queue can choose between two target cells to enter the exit stream (4).

For the analytic analysis we employ a mean field approximation to derive results for the average outflow in dependence of the friction parameter and inflow rates. Due to the Moore neighborhood the merging area of the junction is extended to two cells. Consequently, there exist four different configurations of the intersection. The resulting additional correlations are taken into account via a two-cluster approximation.

Even in this simple case five parameters are required for a realistic modeling of the pedestrian movement:

- 1.The hopping probability (β_1) into the intersection area from stream 1.
- 2.The hopping probability (β_2) into the first cell of the intersection area from stream 2.
- 3.The hopping probability (β_3) into the second cell of the intersection area from stream 2.
- 4.The hopping probability (α) for particles within and out of the intersection area.
- 5.The friction parameter (μ) for solving conflicts as a consequence of the parallel lattice update.

The time-evolution of the occupation probabilities of junction cells is governed by a set of linear equations. In the steady state these equations can be solved analytically. From the stationary solution one can derive the outflow from the junction. We discuss the dependence of the outflow for the various parameters.

Additionally, we also consider a semi-deterministic case where $\alpha = \beta_1 = \beta_2 + \beta_3 = 1$. With this choice of parameters there is no dawdling so that particles will always move ahead if there is an empty cell in front of them. (One can think of this case as an evacuation scenario.) The stochastic component of the system is reduced to the friction parameter and the choice of the target cell of particles from stream 2 and leads to a considerable simplification of the master equation governing the time-evolution.

The analytically derived functional dependence is compared to Monte Carlo simulations of the system. Preliminary results show good agreement between the two approaches.

REFERENCES

[1] A. Kirchner, K. Nishinari, A. Schadschneider: "Friction effects and clogging in a cellular automaton model for pedestrian dynamics", *PhysRevE*.67.056122, 2003

[2] D. Yanagisawa, K. Nishinari: "Mean-field theory for pedestrian outflow through an exit", *PhysRevE*.76.061117, 2007

[3] C. Burstedde, K. Klauck, A. Schadschneider, J. Zittartz: "Simulation of pedestrian dynamics using a two-dimensional cellular automaton". *Physica A* 295 (2001), 507-525

[4] T. Kretz, M. Schreckenberg: "Moore and more and symmetry", In: *Pedestrian and Evacuation Dynamics*, 05, Springer, 2006

Simulation model for vehicle and pedestrian interaction considering road crossing activities

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This paper presents the development of pedestrian model capable to represents from simple to complex pedestrians and vehicles interactions.

The emulation of pedestrians in the traffic environment is a complex problem. In order to represent the real movements of pedestrians, models should be able to simulate several processes, including path planning, sense and avoidance of obstacles, and interaction with other pedestrians. Most research efforts on pedestrian modeling focus on crowd simulation or pedestrian movement and interaction in urban environments (1), and to deal with the complexity of pedestrian movement, authors often use artificial life and cellular automata approaches (2,3).

The simulation of pedestrian behavior and vehicle traffic has traditionally evolved separately, and the association of these research fields is difficult to find in the literature. Pedestrian focused models frequently ignore, or provide simplified representations of vehicle movements. Pedestrian crossings are crucial elements in the traffic systems. The development of sound modeling representations of pedestrian crossings can contribute to improving the efficiency and safety of these facilities (4,5).

A design of a pedestrian model should be adequate to its purpose. It is not possible to cover all activities and peculiarities of the pedestrians, especially in a road crossing environment. The inclusion of unrepresentative variables can impair the models performance and robustness. However, neglecting important aspects could make the study weak and the results unrealistic.

It is important to list different types of pedestrian's and driver's behavior at the time of crossing, classifying them according to their importance and relevance in a pedestrian model, regarding its modeling complexity and computational cost. According to this classification, it is possible to develop a new pedestrian model considering the most important aspects of the pedestrians' road crossing activity.

The interaction between vehicles and pedestrians may present different levels of complexity. The simpler, and more frequently observed environment, consists on situations where pedestrians use sidewalks and cross the road only at traffic lights or pre-defined crossing points. Under these circumstances, there is no longitudinal interaction between pedestrians and vehicles. It is possible to stratify pedestrians' and vehicles' flow, and the interaction between them can be defined by straightforward rules. However, in some circumstances, interaction can achieve an increased level of complexity, generating chaotic states where it is not possible to separate the flow of pedestrians and vehicles. Most models formulations are not capable of representing this chaotic environment.

REFERENCES

- [1] Hao, J., Xu, W., Mao, T., Li, C., Xia, S., Wang, Z., *A semantic environment model for crowd simulation in multilayered complex environment. Virtual Reality Software and Technology archive Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology. Kyoto, Japan, p. 191-198.*
- [2] Hamagami, T. and H. Hirata. *Method of crowd simulation by using multiagent on cellular automata. International Conference on Intelligent Technology, IEEE, 2003.*
- [3] Ronald, N. and L., Sterling. *Modeling pedestrian behavior using the BDI architecture. International Conference on Intelligent Agent Technology (IAT'05), IEEE, 2005.*
- [4] Chae, K.. *Simulation of pedestrian-vehicle interactions at roundabouts. PhD Thesis, North Carolina State University, Raleigh, NC, United States of America, 2005.*
- [5] Chu, X., M. Guttenplan and M. Baltes. *Why people cross where they do: The role of the street environment. Transportation Research Record, v. 1878, 2004, p. 3-10.*
- [6] Meschini, L. And G., Gentile (2009). *Simulation car-pedestrian interactions during mass events with DTA models: The case of Vancouver Winter Olympic Games. International Conference, SIDT, Milan, 2009.*

Poster exhibition

Unsorted list

Nirajan Shiwakoti, Monash University, Melbourne AUSTRALIA

Understanding crowd panic at turning and intersection through model organisms

Daisuke Fukuda, Tokyo Institute of Technology, Tokyo JAPAN

An econometric based pedestrian walking behaviour model implicitly considering strategic or tactical decisions

Stefan Sarstedt, Hochschule für angewandte Wissenschaften, Hamburg GERMANY

WALK: A modular testbed for crowd evacuation simulation

Alexander Kamyshnikov, Siberian Federal University, Krasnoyarsk RUSSIA

Computational complexity and parallel computing in discrete-continuous SIGMA.DC pedestrian movement model

Tuomo Rinne, VTT Technical Research Centre of Finland, Esbo FINLAND

Bottlenecks in evacuation design considering both structural and human behavioural aspects: An experimental study

Cecile Appert-Rolland, University Paris-Sud, Paris FRANCE

A macroscopic model for bidirectional pedestrian flow

Barbara Krausz, Fraunhofer-Institut IAIS, Sankt Augustin GERMANY

Integrating lateral swaying of pedestrians into simulations

Toshiyuki Kaneda, Nagoya Institute of Technology, Nagoya JAPAN

Evacuation agent simulation in underground shopping street adding floor field approach and its three dimensional expression

Understanding crowd panic at turning and intersection through model organisms

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Herding, flocking, schooling and swarming are commonly observed grouping behaviors of animals (1). Activities at transit stations, sport events or religious gatherings are common examples of collective behaviors in human communities under normal, everyday situations. Under panic conditions, such as predator attack, animals try to stay close to each other in order to equalize the risk and reduce chances of being caught by a predator (1). Similar behaviors can be observed in humans during escape from burning building, theatres, stadiums etc. (2). Thus, insights from non-human biological systems may be used to understand the collective human behavior under emergency situations and to enhance the safety of human crowds as described in (3, 4).

The layout of the escape area could have substantial negative effects on collective crowd flow and behaviour, especially under panic conditions, where limited time is available to escape from potential dangers. Although previous studies on crowd disasters have highlighted the importance of considering movement patterns at turning points and at intersection (2), very limited qualitative and quantitative studies have addressed this phenomenon, particularly under panic situations. One reason for this might be the lack of empirical data to validate the predictions from mathematical models (5).

In this work, we use model organisms approach by using empirical data collected from panicking Argentine ants to study crowd panic at turning and intersection. Experiments were conducted with the ants for the different angled corridor (0, 30, 45, 60 and 90) as well as at right angled intersection under panic situation.

From the data analysis, it was observed that the flow does not always decrease proportionately with the increase in turning angles. It shows that there may be optimal angles for maximizing flow and that flexibility on the choice of turning angles can have implications in situations when it is not possible to have straight corridor due to design and/or space restrictions in case of human situation. Similarly, from intersection experiment, it was observed that the most dangerous situation could be when one stream of flow of individuals is blocked by another stream of individuals for considerable time resulting in disproportionate flow at the intersection.

The study demonstrate that the animal models such as ant colonies might allow empirical testing of human pedestrian models when human subjects cannot easily or ethically be employed, providing the model can be scaled appropriately. Successful prediction of collective movement in both species would suggest that common underlying dynamics govern the behaviour of self-driven particles across a wide size range.

REFERENCES

- [1] Okubo, A. *Dynamical Aspects of Animal Grouping: Swarms, Schools, Flocks and Herds*. *Advance in Biophysics*, Vol. 22, 1986, pp. 1-94.
- [2] Chertkoff, M.J. and Kushigian, H.R. *Don't Panic: The psychology of emergency egress and ingress*. Praeger Publishers, USA, 1999
- [3] Shiwakoti, N., M. Sarvi, G. Rose, and M. Burd, M. *Enhancing the safety of pedestrians during emergency egress: Can we learn from biological entities?* In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2137, Transportation Research Board of National Academies, Washington, D.C., 2009, pp. 31–37.
- [4] Shiwakoti N., M. Sarvi, G. Rose, and M. Burd. *Animal dynamics based approach for modeling pedestrian crowd egress under panic conditions*, *Transportation Research Part B*, Vol. 45, 2011, pp. 1433-1449
- [5] Helbing, D., Farkas, I. and Vicsek, T. *Simulating dynamical features of escape panic*. *Nature*, No. 407, pp. 487-490, 2000.

An econometric based pedestrian walking behaviour model implicitly considering strategic or tactical decisions

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Analysing pedestrian behaviour is important for better design of facility, evacuation planning and so on. Previous approaches of modelling pedestrian behaviour can be classified into two directions: (1) cell-based spatial representation (e.g. cellular automata model) and (2) continuous spatial representation (e.g. social force model). As the third direction, econometric-based pedestrian behaviour analysis based on discrete choice model (e.g. Antonini et al. 2006 and Robin et al. 2009) has been recently attracting attention due. This approach is attractive because various influential factors for walking behaviour can be easily incorporated into utility functions and also the calibration of model parameters is rigorous based on econometric theory.

Existing econometric based pedestrian models, however, only consider walking behaviour at operational level and do not deal with any choice decision at strategic level (e.g. destination) or at tactical level (e.g. route). Usually it is assumed that strategic and tactical decisions are exogenously made. In various real situations, however, pedestrians have been intermittently making a decision on re-changing their destinations or routes. For example, video observation at train stations tells that pedestrians who are going through ticket gate would tend to change their target gate en route when the station plaza and the area neighbouring the gate are so crowded.

Another issue on the use of econometric based pedestrian modelling is that in calibration it is costly to collect pedestrian trajectories which are usually manually tracked from video sequences. To some extent, automation in data collection of pedestrian trajectories is highly expected.

In this study, we propose an econometric based pedestrians' walking behaviour model which implicitly consider strategic or tactical decisions. In real situations, it is only possible to observe pedestrians' trajectories and their final choice results on destination (e.g. the ticket gate they actually chosen) and the targeted destination en route are latent and unobservable. To reflect this fact a model of dynamic latent plans (Choudhury et al. 2010) has been extensively utilised by assuming destination choice as a decision at plan level and walking at action level. The latent plans (destination) by pedestrians may dynamically change subject to environment and it further leads to the dynamical and structural change in their action choices (walking trajectories).

The proposed model is validated with the video sequences of pedestrian behaviour which was recorded around a ticket gate at a crowded rail station in Tokyo. For efficient data collection, a generalised state-space modelling approach (particle filter method) is also applied to automatically track walking behaviours from video sequences. The parameter calibration result indicates that the proposed model fits the real data much better than the simple model of walking behaviour. Finally, a pedestrian

simulator is implemented and tested for evaluating pedestrian movements in a larger and more crowded station.

REFERENCES

Antonini, G., Bierlaire, M., Weber, M., 2006. *Discrete choice models of pedestrian walking behavior. Transportation Research Part B* 40 (8), 667–687.

Choudhury, C., Ben-Akiva, M., Abou-Zeid, M., 2010. *Dynamic latent plan models. Journal of Choice Modelling* 3 (2), 50–70.

Robin, T., Antonini, G., Bierlaire, M., Cruz, J., 2009. *Specification, estimation and validation of a pedestrian walking behavior model. Transportation Research Part B: Methodological* 43 (1), 36–56.

WALK: A modular testbed for crowd evacuation simulation

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When large numbers of people gather in public spaces such as stadiums, railway stations, shopping centres and concert halls there is an increased risk of mass emergence and disasters. Critical situations could possibly be prevented with appropriate means to anticipate them. WALK is a modular designed testbed for crowd evacuation simulation developed at the Hamburg University of Applied Sciences. It is designed respecting the requirements of civil defence by allowing the definition and simulation of versatile scenarios with differing environment structure and crowd attributes. In order to simulate individual agents and provide a distribution of the system, WALK is realized as a multi-agent simulation.

Systematic studies of human behaviour in critical situations and quantitative theories capable of predicting crowd dynamics are rare. It is difficult to reenact a disaster or mass crowding in study to watch human panic behaviour closely. Researchers differ in opinion regarding typical behaviour of individuals in critical situations. However, in some areas they agree. Crowding behaviour occurs if resources that are necessary to survive or resources that are very popular are getting scarce. In dangerous situations fear plays an important role. When humans feel threatened, an archaic part of the brain reacts with flight or fight instinct. The performance and power of judgement of the brain decreases. This could potentially result in bottleneck-effects at known exits while alternative emergency exits are overlooked. People will be squashed or trampled to death. To achieve an appropriate simulation of humans with agents, emotions, personality and social dynamics have to be considered.

WALK is based on a flexible component-based architecture. A geographical information system (GIS) provides information about the simulated environment. Information layers are used to distribute required information, e.g. the current air temperature, across the simulation. Agents use these layers as a basis for their perception. One of the key features of WALK is the possibility to define scenarios, which allows a fast and flexible application of the simulation system, e.g. in case of an anticipated terrorist attack. A scenario specification is a complete description of the setting, which includes architecture, size and composition of the crowd and the occurrence of events.

WALK agents will be equipped with components for simulating personality traits, emotion and social interaction to show believable human-like behaviour. A modular agent architecture will allow the replacement of single components. Thus, a comparison of different emotion, personality and social behaviour models will be possible and will help to draw important conclusions about the simulation of human-like behaviour. Consequently, WALK can serve as an inter-disciplinary testbed for scientists from different disciplines like social sciences, psychology and computer science.

In the current state of development, a basic simulation platform is implemented. Simple scenarios can be defined and the GIS provides all necessary information to simulate them. In order to show the simulation state, WALK provides real-time 2D and 3D visualization.

In the near future, a flexible agent architecture to simulate different psychological models will be developed.

Computational complexity and parallel computing in discrete-continuous SIGMA.DC pedestrian movement model

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The paper deals with computational aspects of pedestrian dynamics modelling. The discrete-continuous stochastic floor field model SIGMA.DC is considered [1]. The model simulates movement of a single person in the flow, taking into account other particles, obstacles, strategies (the shortest path and the shortest time), destination, in a continuous space. Number of the possible directions q , where person may move at each time step, is a model parameter. Movement equation is given in a direct form as a function of a previous position and local particle's velocity.

From practical applications of pedestrian movement models continuity of a space is the pros, and cons of continuous models are problems with discretization of the task to realize simulations on computer. The other contributions to the computational complexity of the simulation are given by the number N of people and squares of crowded places, which may reach several tens of thousands.

The following tasks are the most time consuming. The model adopts an idea of using the static floor field S from CA approach [2, 3]. To avoid boundary effect a very fine mesh (up to 1 cm in side size) is used. A special algorithm is used to calculate the field S and save it in RAM.

Pedestrian velocity is density dependent, and in our model this dependence is used in direct form. To estimate local density for each particle in each step and direction we propose to use Monte-Carlo method combined with Nadaraya-Watson's weighted density estimate.

To save computational time and to simulate evacuation on-line or faster (that is very important for comprehensive practical applications) a parallelization of the computational algorithm is used. Comparison of possible parallel implementation of the model (by persons, floors, slices) is discussed. A software implementation of the model is realized using the programming language C++, Qt framework and MPICH2 library for high performance parallel computing.

There was paid attention to program architecture. The calculation engine is made as single executable module that extends the application of the model. For example, for Krasnoyarsk schools we develop a software tool "3D-simulator of fire evacuation" consisting of a computational kernel that sends data to the 3D-visualization program. This simulator is to improve and maintain a pupil's competence in the field of fire safety using the visual game learning form.

REFERENCES

- [1] Kirik, E., T. Yurgel'yan, A. Malyshev. *On discrete-continuous stochastic floor field pedestrian dynamics model SIGMA.DC // In the book "Emergency evacuation of people from buildings", 2011. – pp. 155-161.*
- [2] Kirik, E., Yurgel'yan, T., Krouglov, D. (2011) *On realizing the shortest time strategy in a CA FF pedestrian dynamics model // Cybernetics and Systems, vol.42:01, 1-15.*
- [3] Schadschneider, A., A. Seyfried. *Validation of CA models of pedestrian dynamics with fundamental diagrams // Cybernetics and Systems, Vol. 40 (5), 2009, 367–389.*

Bottlenecks in evacuation design considering both structural and human behavioural aspects: An experimental study

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The quality of data from normal evacuation drills depend strongly on how well the evacuees are informed about the drill beforehand. For instance, pre-movement time distributions might lead to wrong conclusions in well-informed situations. In addition, people movement is dominated by the awareness of familiar routes and no anomalous human behaviour is observed. Usual reason for well-informed drills is that drills are usually held infrequently so there is a fear that something might go wrong if the drill is not well-informed. At the moment, normal fire drills reveal rarely bottlenecks in point of view of fire safety design, but they are useful for building safety organisations and staff for knowing the general level of safety and recognising the weak points. Hopefully, in future the modern safety culture and the way of thinking could lead to the situation where normal fire drills would offer more different test scenarios.

Usually dimensioning problems in evacuation situations relate to bottlenecks, e.g., door geometries, stairs, merging flows, counter flows, and emergency rescue personnel operations. These issues can be demonstrated through fully controlled experimental set-ups. VTT is a coordinator in a project “Evacuation and rescue operations in fire conditions” that will produce experimental data in four different scenarios and geometries. The first geometry relates to stairs, where fatigue, fire fighters’ and normal people counter flows, and fire fighters’ rescue operations in stairs are examined. The second trial will be performed using different door geometries, where the aim is to monitor how prone people are to form a new queue near the doors when selecting a doorway, how certain geometrical arrangements increase specific flows, and what is the effect of door opening forces and angles to the specific flows. Two other scenarios are conducted in corridors, where density of smoke, different lightning conditions, route selections and counter flows are examined on both group and individual levels. The instrumentation consists of normal DV-cameras, RFID-tags, and sensors measuring angular acceleration and door opening forces, and physical stress of the fire fighters. In addition, questionnaires will bring more detailed information to explain individual data and behavioural phenomena.

Experiments will be performed in March 2012 and the persons attending the tests are students of Finnish emergency services college and conscripts, in total 150 persons. Most of the test persons are males, aged 20-30 years old. Depending on the nature of the experiment, the group size varies from 15 to 40 persons. In addition, some of the tests will be conducted on an individual level. The results will be published in the final report that is freely available on internet in the end of year 2012. The preliminary results of the test series without throughout statistical analysis are presented in the poster.

A macroscopic model for bidirectional pedestrian flow

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Sebastien Motsch, University of Maryland, College Park MD USA

This poster presents a macroscopic model for pedestrian dynamics in a corridor (or in any quasi one-dimensional system) [1]. The model is inspired from the Aw-Rascle model of car traffic [2] with the main difference that here, a two-directional flow is considered: in each point, two densities are defined, respectively for left and right going pedestrians. The challenge is to implement a maximal density constraint in order that the density remains bounded even under congestion.

To model the density constraint, we introduce a pressure term, to model the interactions between pedestrians, that diverges when the density approaches the maximal density. The intensity of the divergence is controlled by a small parameter epsilon.

In the limit where epsilon tends to zero, the pressure term becomes singular at the maximal density. Then the system exhibits coexisting phases, with densities either equal to the maximal density (congested phase) or less than the maximal density (uncongested phase). These phases are separated by sharp interfaces.

A variant of the model, for which all pedestrians have the same preferred velocity, allows to have simpler calculations and to illustrate and study both implementations (finite or vanishing epsilon) of the congestion constraint.

The lateral extension of the corridor can be taken into account through a multi-lane model, with appropriate lane changes.

A characteristic of two-way models is that they can loose their hyperbolicity in some cases. Actually, this could be the counterpart of phenomena observed in real crowds, namely the instability of homogeneous flows towards lane-formation, or even crowd turbulence as observed at very high crowd densities [3].

The pressure term appearing in our model could in principle be obtained from experiments. It is also possible with this formalism to have different characteristics for each pedestrian flow. For example, pedestrians heading towards a train platform could be more pushy than those going backwards. This remains to be explored analytically and numerically.

A comparison between the simulations based on this model and an experiment performed in a ring corridor [4] is currently performed [5].

REFERENCES

- [1] C. Appert-Rolland, P. Degond and S. Motsch, „Two-way multi-lane traffic model for pedestrians in corridors“, *Networks and Heterogeneous Media*, vol. 6, p351-381 (2011).
- [2] A. Aw and M. Rascle, „Resurrection of ``Second Order`` Models of Traffic Flow and numerical simulation“, *SIAM Journal on Applied Mathematics*, vol. 60, p916-938 (2000).
- [3] D. Helbing, A. Johansson and H. Zein Al-Abideen, „The Dynamics of Crowd Disasters: An Empirical Study“, *Phys. Rev. E*, vol. 75, p046109 (2007).
- [4] M. Moussaid, E. Guilloit, M. Moreau, J. Fehrenbach, O. Chabiron, S. Lemerrier, J. Pettre, C. Appert-Rolland, P. Degond, and G. Theraulaz. *Outbreak and breakdowns of collective intelligence in human crowds*. submitted to *PLoS Computational Biology*, 2011.
- [5] S. Motsch et al, in preparation.

Integrating lateral swaying of pedestrians into simulations

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Simulations of pedestrian streams play an important role when optimizing evacuation routes or identifying hazardous locations in a building or event location in order to prevent accidents. Obviously, it is of vital importance that simulations are as accurate and realistic as possible. Considering future research directions that integrate real-time information into simulations in order to foresee hazardous situations, prevent accidents, and recommend evacuation strategies in real-time, accurate pedestrian models are even more important.

In order to improve and validate models of pedestrian behavior, insights into human motion characteristics are needed. In particular, the dynamics in locations of high pedestrian density are of great interest. A very characteristic human motion pattern is lateral swaying. From common observations, it is known that people do not move along a straight line, but instead tend to swing laterally. Recently, this characteristic motion pattern has been exploited in order to detect congested areas by analyzing short-term motions from video surveillance cameras [3,4].

However, a comparison of simulated trajectories and real trajectories reveals that lateral swaying has not been adequately taken into account in state-of-the-art pedestrian models. In this work, we extend the generalized centrifugal force model [1,2] by introducing an oscillation force that mimics lateral swaying of pedestrians.

First, we show that there is a linear relationship between the velocity and the amplitude of lateral swaying as well as between the velocity and the frequency. For that purpose, we analyze real trajectories obtained from video recordings of a large scale experiment conducted under laboratory conditions. Next, in addition to the driving force and the repulsive forces proposed in the generalized centrifugal force model, we superimpose an oscillation force using the obtained parameters for frequency and amplitude of lateral swaying. In addition to introducing the oscillation force, we also adapt the ellipse modeling space requirements of pedestrians to a reasonable size.

To quantitatively evaluate the effectiveness of our model, we simulate pedestrian movements and show that the fundamental diagram is well reproduced. Secondly, we employ trajectories obtained from a large-scale experiment under laboratory conditions, use their initial positions and simulate pedestrian movements. A comparison of real trajectories and simulated trajectories reveals that our model simulates realistic trajectories.

REFERENCES

- [1] M. Chraibi and A. Seyfried. *Generalized centrifugal-force model for pedestrian dynamics*. *Phys. Rev. E*, 82(4):046111, 2010.
- [2] M. Chraibi, A. Seyfried, A. Schadschneider, and W. Mackens. *Quantitative description of pedestrian dynamics with a force-based model*. In *Int. Conf. on Web Intelligence and Intelligent Agent Technologies*, 2009.
- [3] B. Krausz and C. Bauckhage. *Automatic detection of dangerous motion behavior in human crowds*. In *AVSS*, 2011.
- [4] B. Krausz and C. Bauckhage. *Loveparade 2010: Automatic video analysis of a crowd disaster*. *CVIU (to appear)*, 2011.

Evacuation agent simulation in underground shopping street adding floor field approach and its three dimensional expression

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In Japan underground shopping streets have been developed in large cities, where citizens have been loved as commuting paths and shopping spaces. However, on the other hand, underground shopping street as a built environment is exposed to vulnerability from the viewpoint of mainly air ventilation and lighting matters, thus sufficient consideration for space design and evacuation strategy are required, especially in the cases of fire and earthquake. In this context, after comprehensive decentralization law enforced in 2000, city governments are empowered the discretion in space design and evacuation strategy on underground streets, so it is expected to be assessed through realistic simulation.

This paper reports a trial of evacuation simulation for examining space design and evacuation strategy in an underground shopping street in downtown Nagoya in the cases of electric lighting blackout. At that time, we employ three-dimensional space expression intelligible for many stakeholders through each process of the simulations.

The authors have already developed a pedestrian agent simulation model that we call ASPF (Agent Simulation of Pedestrian Flows). ASPFver.1 started as a rule-based agent model with 40cm x 40cm cell size on 2D space and a half second per step. ASPFver.2 analyzed Akashi overpass crowd accident; ASPFver.3 realized that agent can walk on a 'pseudo' continuous space for all directions, and ASPFver.4 examined complicated spaces as walking environments in that we let the improved agents walk along the lines in network of waypoints.

Here, considering evacuation in cases of the normal situation is one way flows in principle, when we try to simulate naturalistic evacuation flows, we thought that an introduction of the floor field (static field) potential approach has advantage in the points of convenience and practicality, for reducing computational complexity. So we newly developed ASPFver.5. This model is implemented on an agent-modeling platform artisoc3.0, and each agent behaves with 22 rules for other agents, 14 rules for walls like as ver.4. In ASPFver.5, different from Burstedde et al's probabilistic approach, on every step each agent updates one's direction to the center of the floor cell of the minimum potential value among adjacent 8 cells (Moore neighborhood), and when there are two or more cells of the minimum, this agent doesn't renew one's direction.

Moreover, we evaluated the evacuation performance of each space through simulations in comparison with the results of the cases of the three space shape models based on the actual measurement survey of a underground shopping street in downtown Nagoya. In discussion, we also refer the expandability of the floor field approach toward three-dimensional space.

Poster exhibition

Unsorted list

Charles Thornton, Thunderhead Engineering, Manhattan KS USA
New wayfinding techniques in pathfinder and supporting research

Stavros Katsoulis, Village roadshow group of companies, Athens GREECE
An innovative evacuation system for multiplex cinemas: Case Study “Village roadshow group of companies - Athens“

Henri Hakonen, KONE Corporation, Espoo FINLAND
Simulation models of merging priorities in staircases

Wael Alhalabi, Umm AlQura University, Makkah SAUDI ARABIA
Evacuating a large scale building: A Holy Mosque in Makkah as a case study

Jung-Yup Kim, Korea Institute of Construction Technology, Goyang SOUTH KOREA
Development of smoke control system ensuring safe evacuation through stairwell in high-rise building in Korea

Sergey Kitov, KONE Corporation, Espoo FINLAND
Improving flexibility of agent's path selection in cellular pedestrian flow model

Jaisung Choi, University of Seoul, Seoul SOUTH KOREA
Revision of pedestrian levels of service values based on pedestrian conflicts

Huan-Huan Tian, Shanghai University, Shanghai CHINA
The lattice hydrodynamic model considering the human subconscious behavior for the counter flow

Chan-Sol Ahn, Korea Institute of Construction Technology, Goyang SOUTH KOREA
A study for ventilation capacity of large enclosure considering real fire load

New wayfinding techniques in pathfinder and supporting research

Charles Thornton, Thunderhead Engineering, Manhattan KS USA
Richard O'Konski, Thunderhead Engineering, Manhattan KS USA
Bryan Klein, Thunderhead Engineering, Manhattan KS USA
Brian Hardeman, Thunderhead Engineering, Manhattan KS USA

In this paper, we will discuss improvements to Pathfinder's wayfinding and door selection algorithms. We will also discuss the characteristics of research work that make it possible to validate such improvements in simulation software.

Pathfinder is a commercial agent-based emergency egress simulator. The software includes a user interface, simulator, and 3D visualization system. The wayfinding discussed in this paper is an aspect of the simulator. Occupants moving from their starting location to an exit must choose a route to follow when walking toward their chosen exit. This route selection process (wayfinding) affects the overall simulation results greatly because time spent waiting in queues and time spent walking control the time it takes all occupants to reach their objectives.

Previously, Pathfinder used a simple procedure to perform this wayfinding task. Using the A Star (A*) search algorithm, Pathfinder would calculate, for each occupant, the shortest possible path the occupant could take to exit the model. Because this approach did nothing to account for queue formation at doorways, Pathfinder users had to use a variety of workarounds to encourage occupants to walk a few extra steps to avoid large queue times.

The new wayfinding algorithm in Pathfinder attempts to more accurately simulate the process people use to perform wayfinding in real life. This new version combines distance estimates with the crowding observed in the occupant's current room. The result of this new approach is that occupants are able to re-route based on estimated queue times and select more realistic routes during the simulation.

To implement this new wayfinding algorithm, we had to overcome a variety of unforeseen challenges: backtracking, re-entrant paths, performance, validation, and others. This paper will discuss these challenges and describe their impact on the final wayfinding algorithm.

Validation played a key role throughout the development of these changes. This paper will also discuss how work such as Donald Havener's observational data on pedestrians as they entered an assembly space and Armin Seyfried's work to quantifying many elements of human movement was vital to ensuring that our simulator continued to reflect valid science. It will also discuss the characteristics that made these works particularly helpful in the simulator development context.

An innovative evacuation system for multiplex cinemas: Case Study “Village roadshow group of companies - Athens“

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Athanasios Kosmopoulos, Audit and Quality Assurance Officer, Athens GREECE*

This paper addresses the organizational, procedural as well as the technological issues related with an innovative evacuation system for Village RoadShow Group of Companies in Athens Greece. The paper depicts the requirements needed for this case study system to ensure proper and safe evacuation routes for the public in a multiplex cinema.

A well designed evacuation system should produce clear optical directional signaling in order to guide the audience towards the assigned exit doors and routes in case of an emergency. Statistical data show, with respect to audience behavioral movements, that 60% of all audience in an emergency prefers to follow the previous entry routes rather than the indicated exit ones. In such a case serious injury probability occurs with the conflicting routing of entering and exiting audience. The system responds significantly to the aforementioned risk, ensuring the integrity, and safety of both people involved and infrastructure. It is not to be neglected a 5% of all audiences refusing to move in an emergency process, and the proper system should motivate them towards the proper direction.

The paper describes the procedures deployed for the operation and support of the system involving the human resource factors in terms of training, monitoring and control. As critical factor emerges the need for immediate response of the system partially or totally in the multiplex as far as decision making process is concerned. The paper discusses and analyses the plethora of emergency risks imposed in a multiplex cinema (fire, earthquake, bomb threat, hostage situation etc) and the different related types of evacuation process should be followed respectively. It assesses and forecasts the impact of an evacuation failure both to the company continuity as well as of any collateral damages.

The case study includes a software simulation of different evacuation situations regarding different audience presence in the multiplex. Conclusively the paper focuses on the specific attributes an evacuation system for multiplexes should respect in order to ensure accuracy, verifiability, accountability, security and quality assurance in relation to the relevant international standards in force such as ISO.

Simulation models of merging priorities in staircases

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When evacuating a high-rise building, two streams of evacuees meet at the landings: those who are already descending the stairs and those who are about to enter the staircase through the landing door. In this article, merging of these streams is studied with agent-based simulations using both queuing model and cellular automata.

The queuing model has a first in first out (FIFO) queue on each floor for agents who are about to enter the staircase. The landing has sufficiently space for the agents to enter according to the merging priority. The number of agents in the landing is limited by a maximum density and the flow is limited by a maximum flow, which depends on the width of staircase. In addition, the landing door width on each floor limits the flow of entering agents.

The cellular automata models movements of the agents in detail. This model does not use any fixed merging priorities but the joining is a result of simulated interactions between the agents and the building.

An evacuation of a high-rise building is simulated with both the queuing model and the cellular automata model. For the queuing model, the following merging priorities are used:

- 1) Stream in the staircase has a priority: agents waiting at the floors have to wait until the staircase is empty;
- 2) Stream from the floors has priority: agents in the staircase have to wait until the floor is empty;
- 3) Both streams have equal priority.

The merging priority does not have much effect to total building egress time. In the first case, the upper floors are evacuated more quickly than in the other two cases. The merging priority affects to the queuing and waiting times on the floors. Results of the cellular automata model are compared to queuing model with different merging priorities. Similar agent characteristics are used, but in the cellular automata model, the shapes and sizes of landings are varied. The effect of the landing shape to the merging priority is compared.

Evacuating a large scale building: A Holy Mosque in Makkah as a case study

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The Holy Mosque that located in Makkah, Saudi Arabia, that been expanded over the time. Today it is about 366,168m² and could accommodate more than half a million prayers. It's a multilevel building. The Holy Mosque has more than one hundred gates which be used in peak time to give worshippers ability to reach the four floors of the buildings. Several activity been held inside the building, such as the five prayers that take place daily which need the worshippers to ingress and egress the building and go to practice their normal life when finished. In addition to that, Tawaf, Sai' and some other rituals should be done and taking place inside this building. Annually and during the seasons of Ramadan and Hajj, the Holy Mosque reached its optimum capacity when worshippers present from all over the world to practice their rituals duties. The needed movement of those worshippers and the differences in background, ages, languages, ...etc. need special treatments and plans.

In history, it had been recorded that the Holy Mosque need to be evacuated only in case of war, however, we have to prepare an evacuation plan for worshippers to prevent any harms during stampede and to keep them safe.

This paper will discuss the issue of evacuating the building in case of emergency, and whenever it's needed and to provide assembly area for worshippers. It will go throw the history and bring to the reader attention all accidents that been occur and record in the Holy Mosque. In addition, it will apply some of the international COD to test its ability to be applied on such a building. In addition, it may provide some alternatives to provide a safe building that could accommodate worshippers and to practice their ritual in a safe and comfortable environment.

Development of smoke control system ensuring safe evacuation through stairwell in high-rise building in Korea

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As building becomes larger, taller and more complex due to industrialization and urbanization, it tends to be vulnerable to fire and establishment of effective measures for fire safety is demanded. Especially the fact that the smoke hinders evacuation and fire-fighting activities as well as becomes the major cause of life casualty emphasizes the importance of smoke control system.

In Korea, as one of the fire safety standards designed to secure the evacuation of people in high-rise building, NFSC501A(Design Guide for Smoke Control System of Special Evacuation Stairwell and Lobby) has been proposed, preventing smoke from penetrating into the smoke-free escape route by raising the pressure of the smoke control zone higher than fire area.

To that end, the pressure differential system which raises the pressure of the lobby between accommodation and stair by using centrifugal fan, duct and air supply damper is commonly employed in high-rise building in Korea. The pressure differential system for smoke control should be designed to sustain the pressure differences between stair-lobby and lobby-accommodation within a certain level so as to enable the evacuating people to easily open the doors and in addition to prevent the smoke from penetrating into the smoke-free escape route.

In this study, The field experiments on pressure field in two buildings of 21 stories and 31 stories in summer and winter season with regard to on/off condition of smoke control system and open/close condition of door are carried out to evaluate the performance of smoke control system and evacuation logistics. And New system of smoke control is presented to improve the current system through the analysis of experimental results and the realization of new ideas. The prototype of new smoke control system is made up and applied to test bed for analysis of the system's performance.

Improving flexibility of agent's path selection in cellular pedestrian flow model

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The continuous social force model and cellular automata model are the two main approaches used in simulation of pedestrian flow. In cellular automata models a static field, which stores the distance to a destination for each cell, is normally used for agent's orientation in space. This means that agent's next move is to the neighboring cell that is closest to the destination.

However, this approach may result in unrealistic behavior. Agents tend to select the shortest path and ignore alternative paths even if the shortest path is crowded and an alternative path would be better with respect to, e.g., time to destination. The reason is that agents' decisions are based only on the information about the static field in the nearest cells, and information about alternative paths is simply unavailable for them. Hence, they act like alternative paths do not exist.

This work suggests a new orientation model to make agent behavior more realistic. The idea is to select the next neighboring cell to move to by using a linear combination of the static field value and a value of direction. The value of direction for a given neighborhood cell is determined by the static field value at a look-ahead distance in the direction defined by the neighborhood cell.

Agent behavior is studied using different predefined look-ahead distances, and by assigning different weights to the static field value and the value of direction. The model is calibrated using data from an experimental study. With the new orientation model, the agents behave in a more natural way: the shortest path is still preferred if it is free but alternative paths start to attract the agents if the shortest path gets crowded.

Revision of pedestrian levels of service values based on pedestrian conflicts

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The levels of service (LOS) for pedestrian flows are determined with Korean Highway Capacity Manual in South Korea. Although the pedestrian LOS methodology in KHCM has an advantage of having a simple computational procedure, this methodology seems to involve some shortcomings. For example, pedestrian density was adopted to explain the discomfort in pedestrian flows but appears to be too insensitive to changes in pedestrian volume.

Theoretically, the volume increase required to degrade LOS D to E should be much less than the one for LOS A to B, because the total number of pedestrian conflicts increases rapidly at high volume levels. However, with pedestrian density being insensitive to changes in pedestrian volume, the KHCM methodology is unable to accurately explain the pedestrian discomfort at each LOS level. In fact, a field panel survey carried out in this research reveals that the KHCM methodology will result in LOS values that are quite different from the LOS values perceived by pedestrians.

This research attempts to resolve this problem by realigning the pedestrian density-volume curve on which the pedestrian LOS services are based. In this process, it is found that pedestrian conflict is a more reliable, sensitive, and can explain more accurately the pedestrian discomfort levels according to volume increase. Subsequently pedestrian conflict characteristics are investigated for various pedestrian flows and these results are linked to pedestrian density in order to realign the current density-volume curve. Finally, a revised set of pedestrian LOS are proposed in this research. It is expected that this revision of the pedestrian LOS values will capture the effects on pedestrian discomfort of volume increase on walkways.

The lattice hydrodynamic model considering the human subconscious behavior for the counter flow

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In this paper, based on the two-dimensional lattice hydrodynamic model considering the path change in the bidirectional pedestrian flow, a new lattice hydrodynamic model for the counter flow is proposed. In this model, the pedestrian's habits included that the walkers prefer to walk on the right-hand side of road, and faster walkers are used to overtaking the preceding walkers in the same direction from the left-hand side of the road, are taken account. In our model, p_{cr} , p_{cl} are used to represent the magnitude of the walkers overtaking the preceding walkers from his or her right-hand and left-hand, respectively. p_r , p_l are used to represent the strength walking to the right-hand side or the left-hand side of road.

The computer simulations are carried out. The up and down boundaries are no-flux, the right and left boundaries are periodic. The initial conditions are chosen as follows: $\rho(i, j) = \rho_c = \rho_0 = 0.2$ at $t=0$; then the local densities $\rho(L/2, W/2)$ and $\rho(L/2-1, W/2-1)$ at time $t=1$ are set as 0.1 and 0.3, where L and W is the length and width of the channel, and taking $L=200$, $W=50$. During the simulation, we take $p_r > p_l$ and $p_{cl} > p_{cr}$.

The results of the simulations indicate that, when p_{cr} closes to p_{cl} , the spatial distribution of the total density ρ takes on regularity, and the jam appears. When p_{cr} is apparently smaller than p_{cl} , the spatial distribution of the total density ρ takes on no-regularity, and the lane formation takes on.

A study for ventilation capacity of large enclosure considering real fire load

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This study is intended to evaluate the characteristics of smoke spreading and the appropriateness of evacuation time extended by operation of smoke control system during fire within the underground space of the building structured in compliance with the smoke control system performance criteria from the local fire safety standard, which has been currently applied to the buildings in Korea. Using the heat release per unit weight of the combustibles, a numerical analysis both in case of smoke control system in operation and the system not in operation was carried out at the several different shopping malls. From the viewpoint of securing the evacuation time, the results were compared in an attempt to assess the appropriateness of the fire safety criteria.

