2014

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Original Publication Citation
Collins, A., Elzie, T., Frydenlund, E., & Robinson, R. M. (2014). Do groups matter? An agent-based modeling approach to pedestrian egress. *Transportation Research Procedia, 2*, 430-435. doi:https://doi.org/10.1016/j.trpro.2014.09.051

Available online at www.sciencedirect.com
ScienceDirect
Transportation Research Procedia 2 (2014) 430 – 435
Transportation Research Procedia
www.elsevier.com/locate/procedia

The Conference on Pedestrian and Evacuation Dynamics 2014 (PED2014)

Do groups matter? An agent-based modeling approach to pedestrian egress

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Abstract

Festivals in city parks attended by individuals and families are a universal feature of urban life. These venues often have the common attributes of vendors and other obstacles that restrict pedestrian movement through certain areas, as well as fixed number of exits. In this study, the authors build an agent-based model (ABM) that incorporates group cohesion forces into this type of pedestrian egress scenario. The scenario considered was an evacuation of 500 people through a single exit. This allowed an investigation into the use of two different simulated pedestrian's heading updating rules.

Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences Delft University of Technology

Keywords: pedestrian crowds; evacuation modeling; social groups; social forces; agent-based modeling and simulation

1. Introduction

Festivals in city parks attended by individuals and families are a universal feature of urban life. These venues often have the common attributes of vendors and other obstacles that restrict pedestrian movement through certain areas, as well as fixed number of exits. When determining the layout of a venue, it is important to consider the safety and effectiveness of pedestrian egress. Thus, there is a demand for using simulation to evaluate the different venue designs. There are different approaches to achieve this, from macro-simulation (Henderson (1974), Helbing (1992), Treuille et al. (2006), Bauer et al. (2007)) to meso-simulations (Hanisch et al. (2003)) to micro-simulation (Okazaki (1979), Helbing et al. (2000), Klüpfel et al. (2001)).

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Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences Delft University of Technology
doi:10.1016/j.trpro.2014.09.051

In the early days of pedestrian micro-simulation, the flow of the individuals did not look natural to an observer; the movements were very jumpy and did not appear to replicate the expected flows of pedestrians that are observed in crowds. To overcome this jumpiness, modelers introduced coherent and smoothing functions. The two most famous of these are Reynold's Boids model (Reynolds (1987)) and the Social Forces of Helbing and Molnar (1995). Both of these approaches average out the potential influences on a simulated individual's heading and produce an aesthetically pleasing visualization of the flow of pedestrian movement. One reason for the improved results is that all of the simulated pedestrians tend to have the same directional goals; that is, they are homogeneous. What if the simulated pedestrians were heterogeneous and had different heading objectives like maintaining cohesion within their own individual groups as well?

In this study, the authors use Repast Simphony to build an agent-based model (ABM) that incorporates group cohesion forces into this type of pedestrian egress scenario. The pedestrian agents have two goals: (1) exit the venue and (2) maintain a level of cohesion within their group. The study compares two approaches to updating agent headings while incorporating these two goals. The first approach uses the weighted averaging approach of social forces (Helbing and Molnar (1995)). The second approach considers a discrete stochastic selection approach between the two goals, which is updated at each time-step. The results from this approach were quite surprising. The paper also considers the impact of the level of group cohesion.

Several other researchers have looked at the effects of group dynamics on simulated pedestrian egress (Vizzari et al. (2013), Wijermans et al. (2013), Pluchino et al. (2014)). However, other studies used a weighted average heading approach to dealing with multiple individual pedestrian objectives. We believe that this is the first paper that takes a step-back from the currently accepted approach of weighted averaging headings to consider ways to overcome its limitations. The approach to group dynamics, outlined in this paper, is a simple one for this simple purpose; for a more detailed approach to pedestrian group dynamics, please see Elzie et al. (2014).

The next section discusses the scenario and the model design. This is followed by a discussion on the simulation results. Finally, conclusions are given.

2. Model

The simulation is based on a simple scenario of a large group of people trying to exit an area. The exit is on the other side of a wall which has a single gap in it for the pedestrians to traverse; this gap also has a single pillar in front of it to disturb flow. The scenario is designed to represent a generalizable pedestrian evacuation where individuals leave a non-descript venue through one exit (Fig. 1). The simplicity of the scenario allows for experimentation of heading update algorithms which can later be applied to more specific venues. The evacuees, 500 in this example, must pass through a narrow passage, shown as a gap in the black wall, to reach the red square-shaped exit on the right. There is also a black square pillar placed immediately before the gap. Each group is uniquely colored with the leader outlined in black. Given the sheer number of groups (67 in this example) the coloring between different groups might look very similar. The left-hand side of the diagram shows several groups heading toward the exit led by their leaders. The size of the groups varies from one to fifteen.

On initialization, the simulation splits the pedestrians into groups of size one to fifteen. A leader is selected for the group and, initially, the agents are placed near the leader (on the left-hand side of Fig. 1). If a leader leaves the simulation for any reason, a new leader is randomly selected. At every time-step each individual will move a fixed distance, about half a meter, in the direction of their current heading. The heading is determined by a mechanism within the simulation that has several parts, namely:

- If the pedestrian is within a fixed distance of the leader, then she heads towards the exit.
- If the pedestrian is more than a fixed distance of the leader, then a heading is selected depending on the simulation setup.

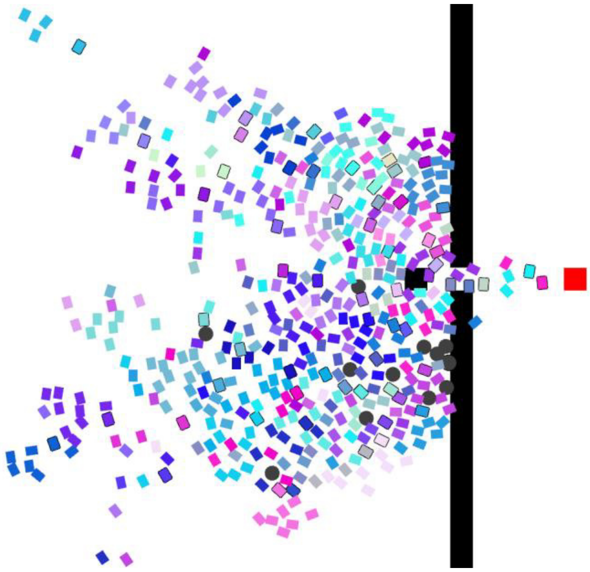

Fig. 1: Screen-shot of evacuation model with the exit is shown as a red square.

This paper considers two heading selection rules. The first is based on the social force model (Helbing and Molnar (1995)) and the second is a stochastic selection between heading options. The first rule can be expressed as:

$$h_i = \lambda . h_i^{CurrentGoal} + (1-\lambda) . h_i^{Leader} \tag{1}$$

Where h_i is the heading chosen for pedestrian i , h^{leader} is the heading toward pedestrian i's leader, and $h^{CurrentGoal}$ is the heading toward pedestrian i's current goal. Lambda is the weighting bias between these two headings. Waypoints are used in the model to ensure that the pedestrians head towards the exit rather than bunching up against the wall. There are three waypoint areas: those just outside the gap, the gap itself, and the exit. This stochastic selection of headings can lead to strange behavior by the agents. For example in Fig. 1, there is one pedestrian waiting on the right-hand side of the gap for their leader to come through. In this case, it does not cause any major issues for the remaining pedestrians. If the pedestrians were standing in the gap, however, the waiting pedestrians would hold up the others and cause a blockage to flow. This blockage prevents the leader from exiting as well, and results in problems for the entire evacuation process.

To overcome this issue, a second rule to heading selections was considered. In this new approach, the pedestrians heading was selected randomly from the two possibilities as follows:

$$h_i = \begin{cases} h_i^{CurrentGoal} & \text{if} \quad X \leq \lambda \\ h_i^{Leader} & \text{if} \quad X > \lambda \end{cases} \tag{2}$$

Where X ~ U(0, 1) is a randomly generated variable updated at each instance it is called. Goal-seeking behavior is a common feature of ABMs, and in this case the approach is justified by requiring agents to choose a heading to reach their intended goal. Naturally, the simulation does not allow the pedestrians to walk through walls or into each other. If an agent's movement would result in collision, he randomly adjusts his until a new unblocked position is found. If no such position exists, the pedestrian chooses not to move. The amount the heading is perturbed is limited to π/2 so that pedestrian remains generally heading in the right direction. This perturbing avoidance aspect of the model is stochastic and, as such, makes all variations of the simulation stochastic.

As mentioned above, the pedestrians will only use equations (1) or (2) (depending on the version of the model) when they are a certain distance from the leader. We refer to this distance as "tightness" of the group. Two levels of tightness where considered in our runs: Loose and Tight. Loose means that the pedestrians can be five persons-equivalent distance (3m) away from the leader; tight means that the try and remain within 1.5 meters of the leader.

3. Results

The model was built in Repast Simphony (North et al. (2006)), which is a Java-based Agent Based Simulation programing environment developed by the Argonne National Lab. Other pedestrian models exist (e.g., Myriad II (www.crowddynamics.com), EXDOS, and PTV Viswalk). Repast Simphony was selected due to its programming flexibility (Java-based) and speed of conducting batch runs (Railsback et al. (2006)).

The Repast Simphony model was run in batch mode on an Intel® Core™ i7-3770 CPU @ 3.40 Ghz with 16GB Ram. Due to the stochastic nature of simulation, each parameter configuration was run 50 times and average results were used. Approximately 13,000 runs were completed. All input parameters were varied. These including weighting bias towards the exit heading, the type of heading update rule used, and the agents' acceptable distance to the leader. Runs that varied both the number of evacuees and maximum group size were also completed but there results are not presented here due to space limitations.

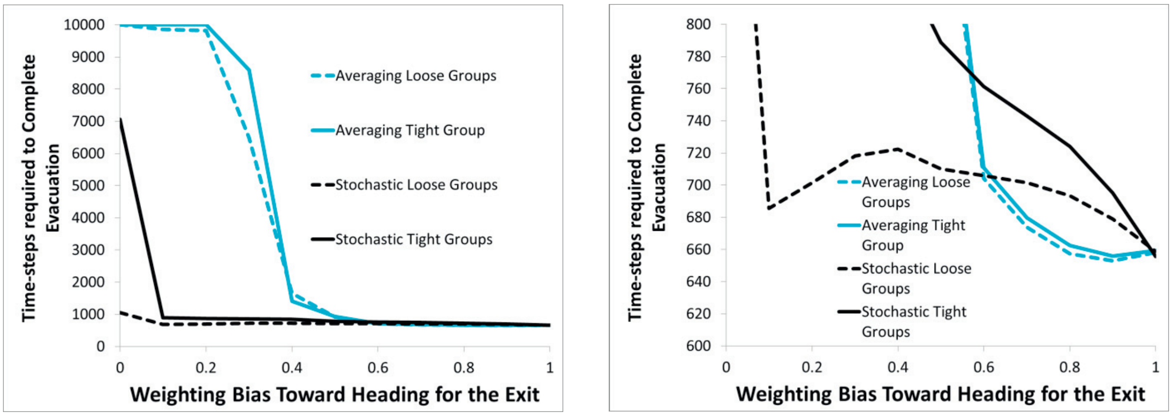

Fig. 2: (a) Graph showing the average number of time-steps required to completely evacuate the agents to the exit, varying over the weighted bias towards heading for the exit. (b) Cut-off Close-up version of the graph in (a).

Fig. 2 shows the results from varying the heading selection rule for different bias towards moving to the exit. The graphs also show the impact of group "tightness." Four different run collections are displayed in the graph, namely: the standard heading averaging rule to determine agent direction with "looseness" (i.e., the agents are not concerned about moving to the leader if they are within five persons distance of the leader), the standard heading averaging rule to determine agent direction with "tightness" (i.e., disregard of the leaders location only happens if the agents are within three persons distance of them), the probabilistic discrete heading selection rule with "looseness," and the stochastic discrete heading selection rule with "tightness." We will now discuss some of the features of this graph and its implications.

As noted previously, lambda assigns the bias between the agent's heading goals (i.e., towards the leader or exit). A lambda of one indicates that all the agents have absolutely no concern about the location of their leader and are only concerned with reaching the exit; this case is equivalent to no groups at all (as its implies no group effects are present in the model). Under a lambda of one, all four run collection should be the same as all pedestrians head only towards the exit (or current waypoint). The results in Fig. 2 confirmed this expected result by showing all four runs converging to the same point when the bias is one. From these runs, we see that it takes approximately 660 time-steps for all the 500 pedestrians to reach the exit.

At the other extreme, lambda equal to zero, we get some surprising results. These results first require a deeper understanding of the simulation. The simulation is limited to 10,000 time-steps. If the simulation reaches that limit, then an evacuation time of 10,000 is reported. This large number of time-steps will only occur if some pedestrians fail to exit, which implies that there is a blockage somewhere near the gap in the wall. This can occur quite regularly in the averaging rule simulation but, due to the randomized nature of the stochastic rule simulations, does not occur as regularly otherwise. The reason for this is the stochastic rule simulations tend to "unclog" themselves because the clogging agent has a non-zero probability to moving towards the exit instead of their leader (there are rounding error issues within the simulation engine relating to lambda equal to zero which results in the non-zero probability).

Between these two extremes (zero and one), interesting differences occur between the two rules. When the bias is toward group cohesion (low lambda), then the stochastic rule results in much faster evacuation times; when the bias is towards the goal of heading to the exit (high lambda), then the traditional averaging rule does better. This result is expected because the traditional rule has no means to deal with pedestrian blockages (i.e. when pedestrians wait in the gap for their leader) but it excels where it is traditionally used (i.e., no or limited group consideration). Thus is a limitation of using traditional approaches because the fail to incorporate group dynamics within their models.

The results discussed require further investigation before any generalizable conclusions can be made of them; as such our results have been presented as anecdotal normative, as opposed to hypothetically descriptive, because further runs and analysis would be required before any confidence can be placed in any statistical test (e.g., determining if there are any heteroskedasticity effects, overcoming the multiplicity problem (Miller (1981)), etc.). However, we can conclude that pedestrian groups do seem to matter.

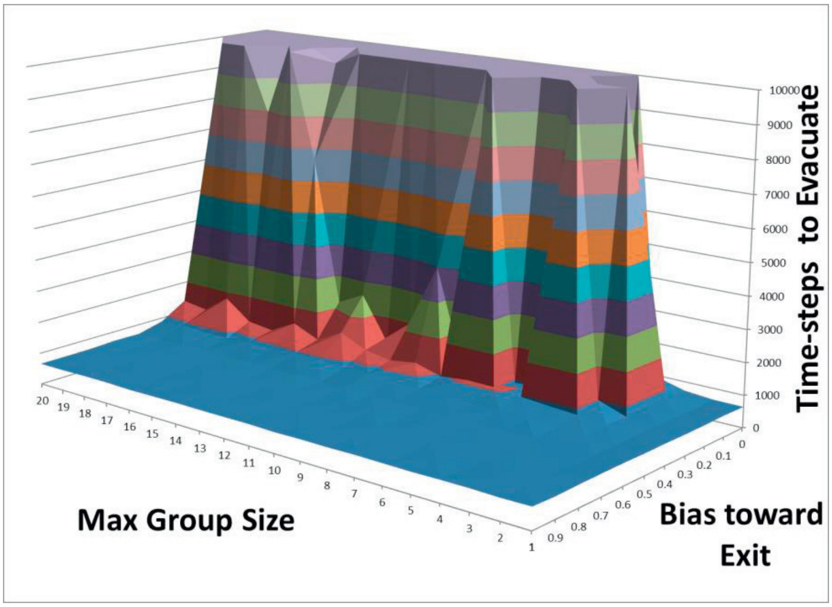

Fig. 3: Graph showing the impact of varying both the maximum group size and weighted bias towards heading for the exit

Some sensitivity analysis was conducted on the results by varying the number of agents and maximum size of group allowed. Some of the results are shown in Fig. 3.

4. Conclusions

The traditional method of updating simulated pedestrian headings, i.e., social forces, becomes less effective when the pedestrians are members of group where cohesions with others is important to each individual. The reason for this lack of effectiveness is that the exit points can get blocked with agents as they attempt to regroup as opposed to heading to the exit. To overcome this issue, a new heading updating mechanism was proposed which randomly chooses a goal to head towards. This approach overcame the blockage problem but is weak in several areas. In particular, it is not that effective when group cohesion is of little importance to the pedestrians and it results in a zig-zag movement pattern of the simulated pedestrians. Thus there is a further requirement to investigate this blockage issue. One candidate is Agent_zero (Epstein (2014)) which takes into account multiple aspects of a simulated agents decision-making process. The results presented here show that goal dynamics matter in pedestrian simulation and are worthy of further study.

5. References

Bauer, D., Seer, S., Brändle, N., 2007. Macroscopic pedestrian flow simulation for designing crowd control measures in public transport after special events, 2007 summer computer simulation conference, San Diego, CA,. 1035-1042.

Elzie, T., Frydenlund, E., Collins, A.J., Robinson, R.M., 2014. How Individual and Group Dynamics Affect Decision Making, 2014 National Evacuation Conference, New Orleans, LA.

Epstein, J. M., 2014. Agent_Zero: Toward Neurocognitive Foundations for Generative Social Science, Princeton University Press.

Hanisch, A., Tolujew, J., Richter, K., Schulze, T., 2003. Online simulation of pedestrian flow in public buildings, 1635-1641.

Helbing, D., 1992. A fluid dynamic model for the movement of pedestrians, Complex Systems 6**,** 391-415.

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

Helbing, D., Molnar, P., 1995. Social force model for pedestrian dynamics, Physical review E, 51.

Henderson, L., 1974. On the fluid mechanics of human crowd motion, Transportation research 8**,** 509-515.

Klüpfel, H., Meyer-König, T., Wahle, J., Schreckenberg, M., 2001. Microscopic simulation of evacuation processes on passenger ships. Theory and practical issues on cellular automatak, Springer.

Miller, R. G. 1981. Simultaneous Statistical Inference. 2nd ed. New York, NY: Springer-Verlag.

North, M.J., Collier, N.T., Vos, J.R., 2006. Experiences creating three implementations of the repast agent modeling toolkit, ACM Transactions on Modeling and Computer Simulation (TOMACS) 16**,** 1-25.

Okazaki, S., 1979. A study of pedestrian movement in architectural space, Part 1: Pedestrian movement by the application on of magnetic models, Trans. of AIJ 283**,** 111-119.

Pluchino, A., Garofalo, C., Inturri, G., Rapisarda, A., Ignaccolo, M., 2014. Agent-Based Simulation of Pedestrian Behaviour in Closed Spaces: A Museum Case Study, Journal of Artificial Societies and Social Simulation, 17**,** 16.

Railsback, S.F., Lytinen, S.L., Jackson, S.K., 2006. Agent-based Simulation Platforms: Review and Development Recommendations, SIMULATION, 82**,** 609-623.

Reynolds, C.W., 1987. Flocks, herds and schools: A distributed behavioral model, New York, NY: ACM, 25-34.

Treuille, A., Cooper, S., Popović, Z., 2006. Continuum crowds, ACM SIGGRAPH, 1160-1168.

Vizzari, G., Manenti, L., Crociani, L., 2013. Adaptive pedestrian behaviour for the preservation of group cohesion, Complex Adaptive Systems Modeling 1**,** 1-29.

Wijermans, N., Jorna, R., Jager, W., Van Vliet, T., Adang, O., 2013. CROSS: Modelling Crowd Behaviour with Social-Cognitive Agents, Journal of Artificial Societies and Social Simulation 16**,** 1.