Literature Review: CSE 6730 Project 1

Chris Dunlap, Allen Koh, Matt May

February 2016

1 Problem Statement

The efficient evacuation of physical structures is an important problem with a long history of multi-disciplinary study [12]. For this study, we focus specifically on the problem of efficiently evacuating the area around Bobby Dodd Stadium in Atlanta, GA. Bobby Dodd Stadium, the home of the the NCAA Division-I Georgia Tech Yellow Jackets football team, has a seating capacity of 55,000 individuals.

Figure 1: Bobby Stadium Stadium seating chart.

Our primary objective in this study is to minimize the pedestrian evacuation time of the stadium and its surrounding area by attendees following a home football game. We do this by taking a parametric approach, in which

1

we explore the effects of road closures, strategically placed guidance symbols (i.e., signs), and the "takeover" of certain intersections by law enforcement in promoting an optimal result.

For purposes of this study, we define the system under investigation (SUI) as a rectangular polygon (Fig. 2) surrounding the stadium. To be clear, the SUI is defined as the area outside the stadium, and not inclusive of the stadium itself.

Figure 2: The system under investigation.

The stadium has 10 "gates," which serve as ingress (pre-game) and egress (post-game) sites. For the purposes of modeling egress, we choose to collapse adjacent gates together, as it seems likely a similar approach would be taken in reality.

For purposes of modeling egress, we assume pedestrian interarrival time at the gate boundary is a homogenous stochastic process that follows a *TODO: insert* distribution. As pedestrians arrive at the gate boundary, and enter

2

the system under investi

2   Related Work

A variety of techniques have been used to model pedestrian movement. Cellular automata, lattice gas, social force, fluid-dynamic, agent-based, game-theoretic, and animal experimention-based approaches have been used [12]. As noted by Zheng, Zhong, and Liu [12], models often encounter or attempt to model several common phenomenoma: clogging, side-stepping, lane formation, and herding behavior, among them.

These phenomena manifest themselves in different ways and at different magnitudes depending on the system being modeled. In one of the early explorations of 2D cellular automata for simulating traffic flow in the related domain of vehicular traffic simulation, Biham and Middleton [1] note the presence of a sharp *jamming transition* in which all cars in the simulation transition from moving at maximal speed to being stuck. Similar effects were noted in simulations of bi-directional pedestrian movement, with Weifeng, Lizhong, and Weicheng [11] finding that as total pedestrian density increases, a critical value is reached at which the system transitions into a jammed state where only a few pedestrians are able to proceed.

In a slightly different take on the problem, Okazaki and Matsushita [10] modeled pedestrian evacuation using Coulomb's Law, with actors magnetically moving toward their goals and away from obstacles that would lead to collisions. In another application of equations of natural phenomena, Helbing [5] derived fluid dynamic equations for explaining the movement of pedestrian crowds, observing phenomena such as the development of lanes, jamming, and crossing. Helbing [7] further notes an explicit "faster-is-slower" effect, in which attempting to move faster results in a smaller average speed of leaving at high pedestrian density in evacuation scenarios.

In a more recent study, Helbing et al. [6] use a "social force" model, which states that pedestrians operate in some sense automatically when reacting to obstacles and other pedestrians, applying strategies that have been learned to be most effective over time. Several suggestions are made to alleviate the three most common problems in pedestrian crowds: counterflows, bottlenecks, and intersecting flows. The presence of strategically placed obstacles are found to actually reduce these negative phenomena, leading to improved flow.

Building on previous cellular automata-based models, Burstedde et al. [3] introduce a *floor field*, a secondary grid of cells which underlies the main grid and acts as a substitute for pedestrian intelligence. These fields can be either static or dynamic, and are capable of promoting the avoidance of jams, as well as simulating attractive effects, in which pedestrians are more likely to follow in the paths of pedestrians ahead of them.

Taking a more algorithmic approach, Fang et al. [4] have designed a modified ant colony optimization (ACO) algorithm for optimizing pedestrian evacuation, seeking to minimize evacuation time, evacuation distance, and congestion. Kemloh Wagoum, Seyfried, and Holl [8] utilize an observation principle approach in modeling pedestrian evacuation, in which pedestrians first observe their environment and then make a final decision on strategy based on obtained data.

There are several takeaways from the literature described above that have potential applicability to the model at hand. First, on the topic of modeling pedestrian walkways, several papers focused on either a single passageway, enclosed areas with obstacles (walls, pillars, etc.), or evacuation from a room with a single doorway. However, modeling walkways as a directed graph [4] seems feasible given the problem at hand, where there are multiple pathways one can take to get to a single destination. In papers where cellular automata was utilized, the median size of each cell on the walkway was $0.4m^2$ [2,3,11].

Second, on the topic of pedestrian modeling, multiple walking speed techniques were used, ranging from a constant speed of 1 m/s [11] or 1.3 m/s [3], to using a distribution resembling a step function [2] or a Normal distribution [9]. In either distribution, the median walking speed was also approximately 1.3 m/s. For reaction to stimuli, 0.3 seconds was utilized [3], which was one time step in that particular simulation. Incorporation of opportunistic side-stepping was done [2], in addition to using least-cost algorithms for establishing the path a pedestrian would like to take [4]. In the context of cellular automata, analyzing a given pedestrian's cell's neighbors in either a 4-connected [11] or 8-connected fashion [3] to decide in which direction the pedestrian would like to walk for the next time step was utilized. This, coupled with a dynamic floor field [3] to factor in long-distance forces, could be utilized.

Finally, simulation execution practices were also gleaned. Care must be taken to do parallel-based updating to avoid sequential updating from interfering with underlying model execution [2]. The practice of using a deterministic model running with randomized initial conditions has precedent [1].

Finally, to achieve statistical significance, 20 runs per configuration has been used [2].

3 Conceptual Model

For purposes of this simulation, we define the . Our simulation is simplified by focusing only on *pedestrian* traffic, avoiding the inclusion of vehicular traffic. In future studies, this could be included as an enhancement.

References

[1] Ofer Biham, A Alan Middleton, and Dov Levine. Self-organization and a dynamical transition in traffic-flow models. *Physical Review A*, 46(10):R6124, 1992.

[2] Victor J Blue and Jeffrey L Adler. Cellular automata microsimulation for modeling bi-directional pedestrian walkways. *Transportation Research Part B: Methodological*, 35(3):293–312, 2001.

[3] Carsten Burstedde, Kai Klauck, Andreas Schadschneider, and Johannes Zittartz. Simulation of pedestrian dynamics using a two-dimensional cellular automaton. *Physica A: Statistical Mechanics and its Applications*, 295(3):507–525, 2001.

[4] Zhixiang Fang, Xinlu Zong, Qingquan Li, Qiuping Li, and Shengwu Xiong. Hierarchical multi-objective evacuation routing in stadium using ant colony optimization approach. *Journal of Transport Geography*, 19(3):443–451, 2011.

[5] Dirk Helbing. A fluid dynamic model for the movement of pedestrians. *arXiv preprint cond-mat/9805213*, 1998.

[6] Dirk Helbing, Lubos Buzna, Anders Johansson, and Torsten Werner. Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions. *Transportation science*, 39(1):1–24, 2005.

[7] Dirk Helbing, Illés Farkas, and Tamas Vicsek. Simulating dynamical features of escape panic. *Nature*, 407(6803):487–490, 2000.

[8] Armel Ulrich Kemloh Wagoum, Armin Seyfried, and Stefan Holl. Modeling the dynamic route choice of pedestrians to assess the criticality of building evacuation. *Advances in Complex Systems*, 15(07):1250029, 2012.

[9] Hubert Klüpfel, Michael Schreckenberg, and Tim Meyer-König. Models for crowd movement and egress simulation. In *Traffic and Granular Flow'03*, pages 357–372. Springer, 2005.

[10] Shigeyuki Okazaki and Satoshi Matsushita. A study of simulation model for pedestrian movement with evacuation and queuing. In *International Conference on Engineering for Crowd Safety*, pages 271–280, 1993.

[11] Fang Weifeng, Yang Lizhong, and Fan Weicheng. Simulation of bi-direction pedestrian movement using a cellular automata model. *Physica A: Statistical Mechanics and its Applications*, 321(3):633–640, 2003.

[12] Xiaoping Zheng, Tingkuan Zhong, and Mengting Liu. Modeling crowd evacuation of a building based on seven methodological approaches. *Building and Environment*, 44(3):437–445, 2009.