Dynamical Cellular Automaton model for simulation of the pedestrian egress from a stadium

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Abstract This project is intended for simulation of pedestrian egress of Georgia Tech Bobby Dodd Stadium after a football game. An efficient evacuation plan will be come up with the simulation to optimize the evacuation time. A stochastic cellular automata model would be developed incorporating the individual behavior of pedestrians.

With the goal of simulating people leaving Bobby Dodd Stadium after a football game, and of minimizing the total egression time, we adjust our conceptual model by changing the state, i.e. stay open or close off, of three surrounding street: Cherry Street NW, Bobby Dodd Way NW, and Techwood Dr NW. Note that North Avenue NW is considered main road, and will always stay open, such that pedestrian could only cross the street using crosswalk with obeying to the traffic signal, or using the foot bridge located between Cherry St and Techwood Dr. For the purpose of understanding and comparing the simulation results, and of verification and validation of our model, we output visualize models and 2D charts, under three scenarios: all three streets remaining open with vehicle runing; all three streets closed off to help with evacuation; closing off only Bobby Dodd Way and Techwood Dr.

i. Assumptions

1) Assume the expected number of people egress from stadium is 30 per unit time step (0.3 second) for 10 exits of the stadium.
2) People's movement inside the stadium is not modelled. Assume each stadium exit has the same flow distribution over time when there is no congestions at the exit.
3) Assume the group size is always one.
4) Assume all entities have two levels of walking speed: when the density of pedestrians are lower than a threshold, pedestrians tend to walk twice as fast the condition with a high pedestrian density.
5) Once a congestion take place at the stadium exits, assume people who are inside the stadium about to come out, are temporarily paused from the evacuating process.
6) People are randomly assigned a final destination with equal probability (the possible destinations are limited to Marta station, several on campus dormitories and several campus parking lots).
7) Assume people always obey crosswalk signals; Once traffic signal turns red, pedestrians who on the crossing area will reach the other side immediately, and the crossing will be cleared.
8) Assume that the transitional probability of each possible cell (the matrix of preference) is combined with the static floor field and the dynamic floor field. The implicit assumption is the choice of pedestrian depends both on the distance from the exist and on the social influence by the surrounding population.
9) All the stadium exits are modeled as vertical or horizontal lines.
10)All pedestrians are familiar with the fastest route to their own destinations.

ii. Simplified Geographic Model

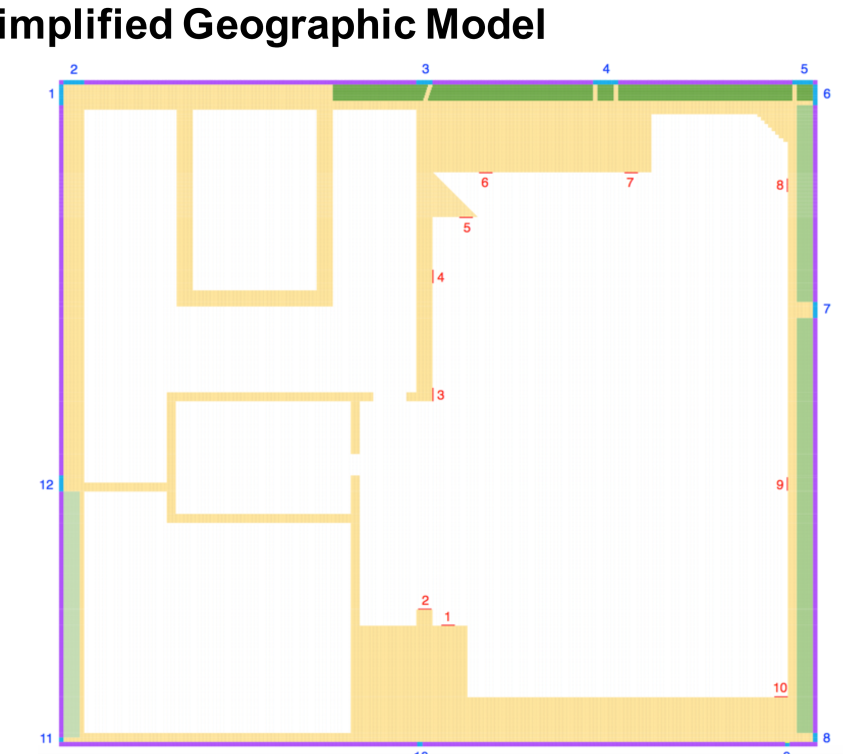


Figure 1 Map of our geographic model
White area represents non-walking zone, i.e. buildings, trees, etc.
Yellow area represents walking zone.
Green area represents roadway that could either stay open or be closed off.
Purple lines are the boundaries, approaching which represent successfully evacuate.
Red short lines, with numbering, represent the 10 stadium exits.
Blue short lines, with numbering, represent the 12 destinations.
Orange numbers denote traffic signals within the analyzed area.

iii. Poisson distribution of pedestrian crowd statistics

Many event data showed that the Poisson distribution is a good approximation for the collective crowd behavior. The typical scene of the applications includes the airport, the train stations, the stadium egress or the event evacuation. Therefore, introducing Poisson distribution into our model is significant to approach the real situations of those events. In other words, a pedestrian emerging into each exit of the stadium follows a Poisson process in time, the potential distribution of which is:

$$P(k,\lambda) = \lambda^k e^{-\lambda}/k!$$

where k is the number of people which go through the exit of the stadium towards their desired destinations, and is the expected number or average amount of the people going through the exit of the stadium during a certain time period (or unit time as we set in the model). queuing theory usually satisfy the Poisson distribution for the behavior pattern [7], and the average effect during a time period is measurable and significant in macroscopic time scale, the Poisson can bring a congestion to form queues if we concern the capacity of a queue is finite

iv. Random Generator

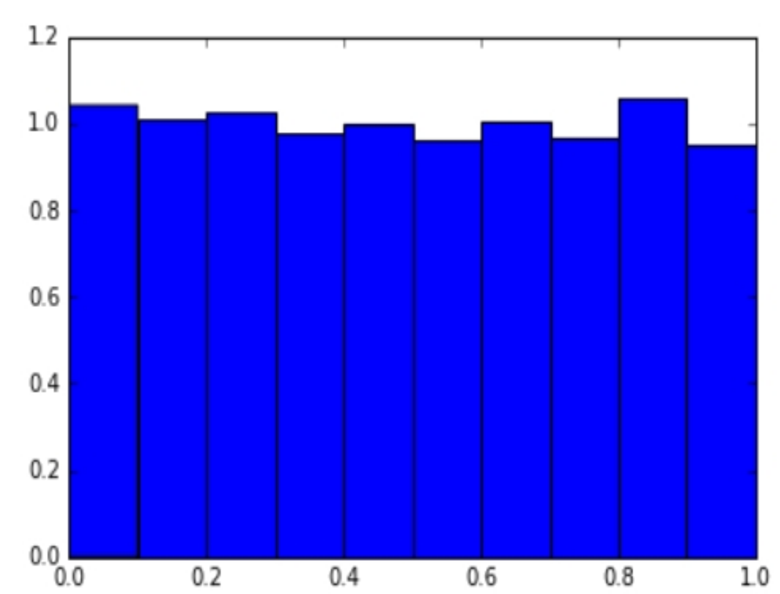


Figure 2. This histogram shows that the numbers generated by the random generator almost follow the uniform distribution during 0~1, and the y axis the normalized frequency of different random numbers whose value falls to one of the bins shown in the x axis. Each bins has about 1000 samples and the total number of bins are 10. From the histogram plot, we have validated that the random generator can generate numbers with a uniform distribution. The random number generator is applied to two process, the first is to assign one destination randomly to the people who arrives to any exit of the stadium. the second scenario is when we calculate the scores of the preference matrix, we introduced random numbers to weighted scores of the preference matrix. We used lehmer algorithm, which is on our final report.

v. Preference Matrix

Calculation of preference matrix is the most critical component in our simulation since it directly determine the behaviors of pedestrians. Overall, as shown in Figure 3 and 4 below, our preference matrix could be either 5 by 5 (when the speed is 2) or 3 by 3 (when the speed is 1) based on the density of its neighborhood cells.

$M_{1,1}$	$M_{1,2}$	$M_{1,3}$	$M_{1,4}$	$M_{1,5}$
$M_{2,1}$	$M_{2,2}$	$M_{2,3}$	$M_{2,4}$	$M_{2,5}$
$M_{3,1}$	$M_{3,2}$	$M_{3,3}$	$M_{3,4}$	$M_{3,5}$
$M_{4,1}$	$M_{4,2}$	$M_{4,3}$	$M_{4,4}$	$M_{1,1}$
$M_{5,1}$	$M_{5,2}$	$M_{5,3}$	$M_{5,4}$	$M_{1,1}$

$M_{1,1}$	$M_{1,2}$	$M_{1,3}$
$M_{2,1}$	$M_{2,2}$	$M_{2,3}$
$M_{3,1}$	$M_{3,2}$	$M_{3,3}$

Figure 3 5 by 5 Preference Matrix **Figure 4** 3 by 3 Preference Matrix

The basic formula for calculating the preference matrix is shown in Figure 5 below. In the formula, the Si,j is the static field score that measures the distance decrease if the pedestrian moves from its standing point to i,j cell. Si,j is only positive when the pedestrian move to the cell that is closer to his destination (exit) compared to his standing cell. For the other cases, this Si,j is set to 0 thus the preference matrix is purely determined by random number. As for the dynamic field score, it's for modeling the interaction between pedestrians -- the pedestrians later tend to follow the former pedestrians' movement if they intend to move in the same direction (e.g the same exit or destination). Dynamic field score will increase by one if it's occupied at that time step. And this score decays with a factor of 0.5 at each time step. ni,j in the formula represents the state of the target cell, which is 1 when occupied and 0 when unoccupied. Finally, for the random number, when the static field score is larger than 0, the simulation program will generate a random number from 1 to 2 to ensure that if the pedestrian could walk a cell that is closer to the exit, he will move there. In all the other cases (move to the cell that has distance to exits equal to standing point or larger than standing point), a random number from 0 to 1 will be generated so that the pedestrian can move randomly.

$$M_{i,j} = S_{i,j} * D_{i,j} * (1 - n_{i,j}) + random\ number$$

$$S_{i,j} = \begin{cases} Decrease\ of\ distance & ,if\ cell\ i,j\ is\ closer\ to\ exit\ compared\ to\ standing\ point \\ 0, & otherwise \end{cases}$$

Figure 5 Formula for Calculating Transition Probability in Preference Matrix

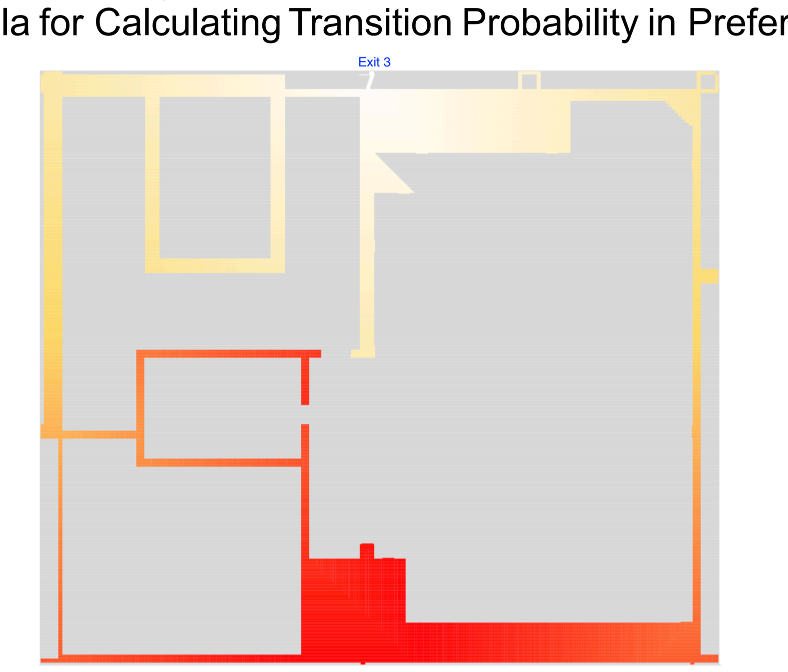
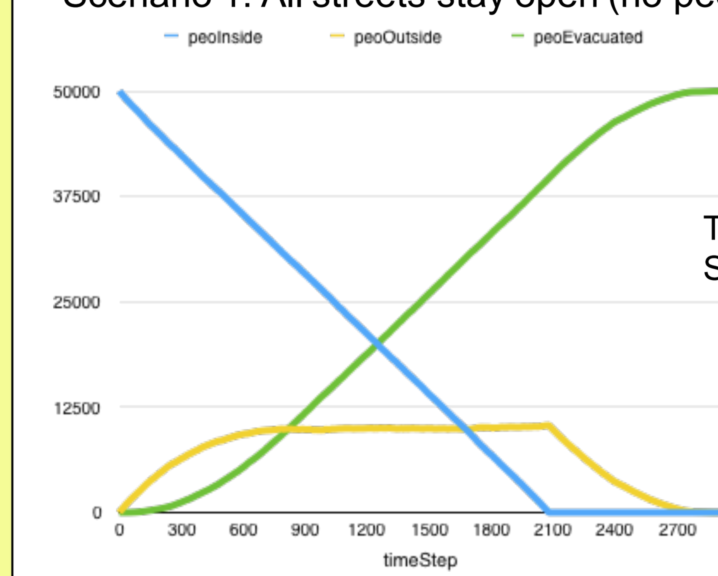


Figure 6 A visualized map of $S_{i,j}$ for exit #3(darker color means larger distance)

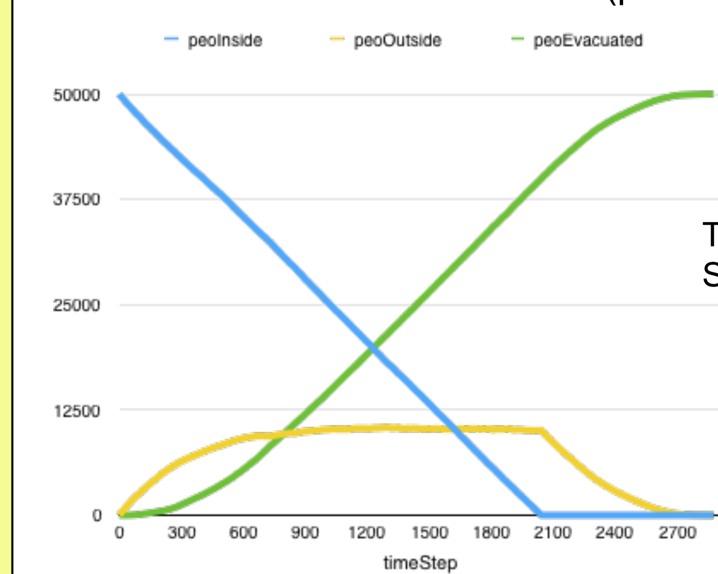
vi. Results and Comparison

Scenario 1: All streets stay open (no pedestrian on roadways)



Total egression time: 874.2s
Stadium egression time: 623.7s

Scenario 2: All streets closed off (pedestrian may be on roadways)



Total egression time: 863.1s
Stadium egression time: 612.6s

The peopleOutside (outside of stadium) line denote that the people remaining outside of the stadium would increase to some number and stay stable for a long time. After people inside the stadium totally evacuated, number of people outside drop down.

From the comparison of the total egression time and stadium egression time between scenario1 and scenario2 above, we may notice that the egression process in scenario2 is faster than in scenario1. So closing off street could help speed up the process.

References

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