Using Computer Simulations to Improve Crowd Flow in a Stadium Environment

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Abstract

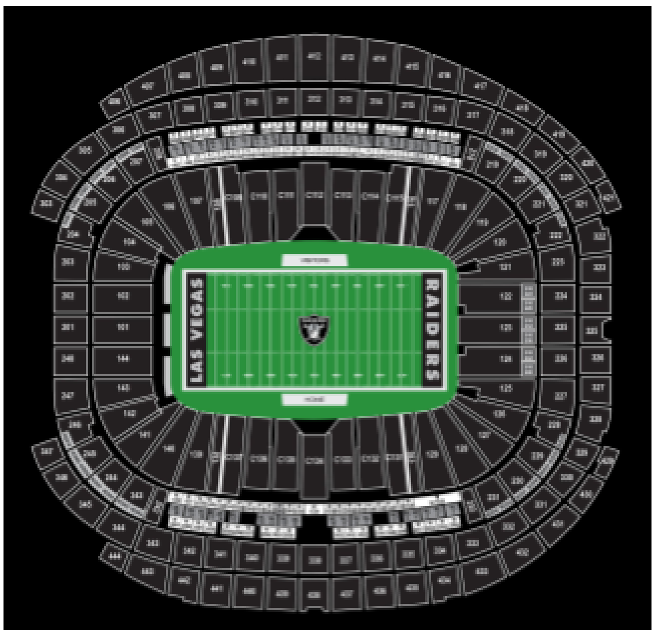
I created a model of a stadium according to the description provided in the problem statement. I used agent-based crowd simulation techniques to analyze crowd flow during stadium egress. I identified areas of the stadium in which simple, low-cost changes could be made to improve customer satisfaction and exit safety. These changes were then tested using a computer simulation at both 100% and 50% of operating capacity to judge their effectiveness. Data was collected on the time required to completely exit from the stadium in each case. I then made recommendations on how to improve the stadium based on the collected data and existing research in the field. I found that assigned parking and exits are a viable low-cost system which improves exiting speed.

Introduction

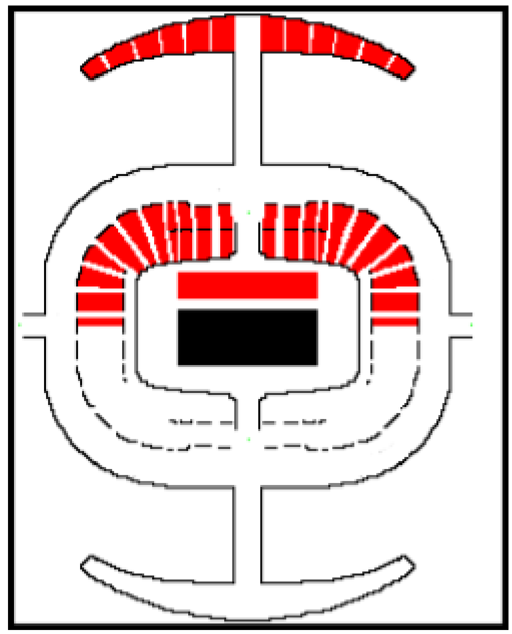
Effective crowd management is vital in stadiums and other large entertainment venues. The experience of entering and leaving the stadium (a.k.a access proximity) is an important part of customer satisfaction[2]. Additionally, poor crowd management poses COVID-19 and crush-related issues. In an emergency, poorly planned crowd evacuation can lead to the deaths of hundreds of people[3]. Previous research involving computer simulations on stadium evacuation and general safety is generally focused on exit size and number[10], hallway design[8], and other structural changes. However, such analyses are often specific to the stadium in question, and involve costly structural changes. The use of computer simulations, a common tool in such research[4][10][8], may be extended to analyze crowd flow during stadium egress with several low-cost, non-structural solutions in place.

Methodology

I chose the Allegiant Stadium in Las Vegas, Nevada as our model due to its similarity to the given seating capacity of 50,000 seats. The stadium floor plan (Fig. 1) was retrieved from the



(Fig. 1) Allegiant Stadium Floor Plan



(Fig. 2) Model Floor Plan

stadium website[1]. I then used GIMP, an image editing software, to create a floor plan (Fig. 2) that more accurately represented the stated shape and seating capacity given in the problem statement. In the conversion, three major aspects of the layout were preserved: the exit locations, walls, and seating areas. Black pixels represented walls, red pixels represented seating areas, and green pixels represented exits. The layout was further altered to contain the long staircase connected to the upper seating area. A stage represented by a large rectangle of walls was added to the field, along with additional seating.

To model crowd flow, an agent-based simulation was used. Each agent was given a path computed at 1-meter resolution, updated each time step. The paths were precomputed by a modified version of Dijkstra's Algorithm[6] which avoided seating areas. On each time step, every agent selected a new position to move to by maximizing a cost function which balanced changing direction with slowing down over the set of unobstructed possible positions, as described in “A Simple and Realistic Pedestrian Model for Crowd Simulation and Application”[7]. Agent behavior was extended beyond this work by the addition of agent tendency to move away from other agents and to change exits when stuck in crowds.

Agents were initially placed in the seating areas at a density of 3-4 people per square meter, a seating density selected by examining existing installations[5]. The simulation was then conducted until all agents had exited the stadium. A video of the egress was generated, and the elapsed time was recorded. This process was repeated with different exit strategies in place. Trials were conducted at both 100% and 50% stadium capacity to determine the effectiveness of these strategies during different operational scenarios.

The source code is available on GitHub.

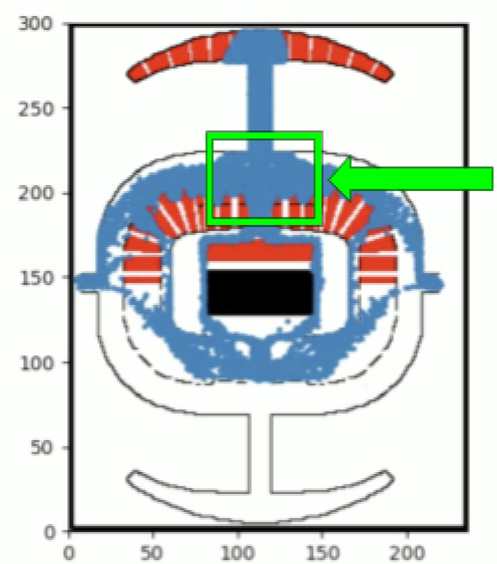
Results

An unregulated stadium environment functioned as our control. In such an environment, each person may be treated as selecting a random exit. When someone leaves the stadium, they will likely take the path they took to reach their seats, which is mainly determined by where they parked. As parking location has little to no correlation with seating location, exit selection may be considered random.

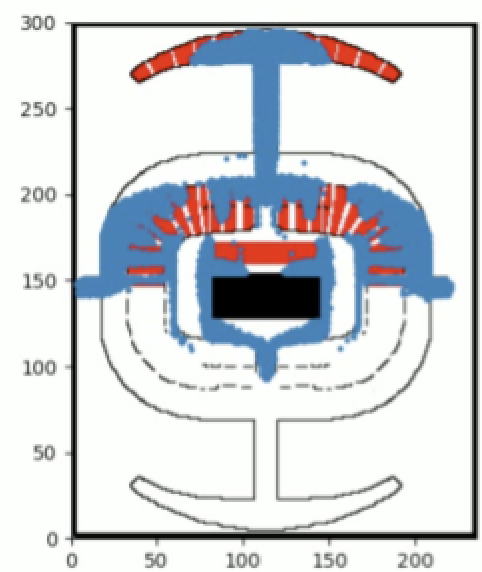
I considered three alternative organizational systems to improve stadium performance. In the first, each person tries to exit through the nearest exit to their seat. In the second, the equal split case, each exit receives an equal amount of traffic. In the third, agents in the upper level of the stadium were delayed by either 60 or 180 seconds.

The results of the simulation are summarized in Table 1.

Table 1					
Exit strategy	Random exit (control)	Nearest exit	Equal split	60s delay	180s delay
Time(s) 100% full	723[video]	688[video]	530[video]	788[video]	825[video]
Time(s) 50% full	522[video]	358[video]	342[video]	509[video]	522[video]
% of control	100.0	81.9	69.4	103.2	107.1

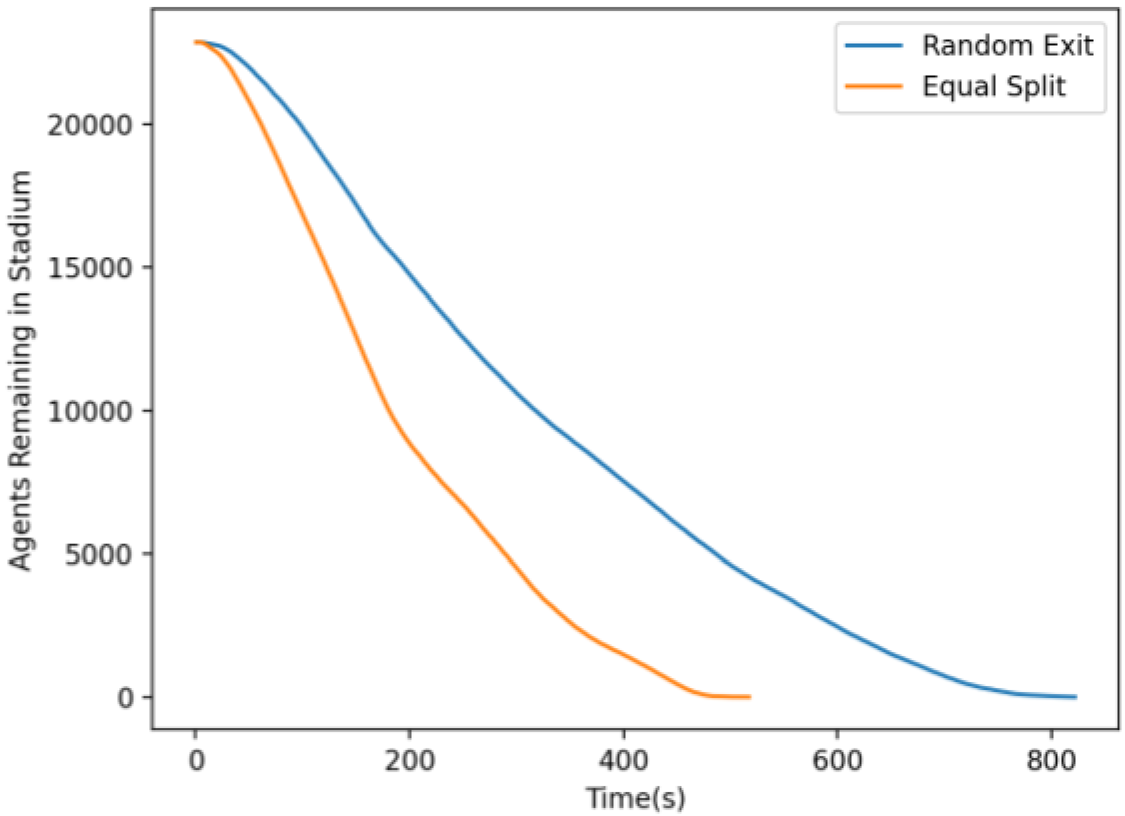


(Fig. 3) Congestion during random exit trials



(Fig. 4) Even crowd split

In the random exit selection case, congestion often occurred in the hallways leading to the exits, as groups of agents had difficulty passing by one another when going in different directions (Fig. 3). The equally split trials displayed much less congestion, resulting in higher efficiency (Fig. 4). This is also visible in the remaining population vs time graph for the random exit and equal split scenarios (Fig. 5).



(Fig. 5) Remaining agents in stadium vs time for random exit and equal split scenarios

Discussion

These results demonstrate that assigning equal groups of people to each exit can improve exit efficiency by more than 30%. Delaying certain groups actually decreases exit speed rather than reducing jams. Assigned exits may be accomplished with assigned parking spaces and exits corresponding to seating section, indicated on tickets. To ensure further compliance, easily affordable blockades[9] may also be put in place to guide customers into the correct exit. This can be accomplished with only slight restructuring of existing ticket management systems and operating procedures. Barriers are already used in stadiums, and can be easily adapted for this purpose. One potential issue with this solution is that it may increase parking lot congestion, as people will have to park in specific areas not necessarily correlated with the direction they arrive and leave from.

Conclusions

The use of assigned exits and parking spaces designated by ticket can be used to improve crowd flow during stadium egress by over 30%. I recommend that in the case of the stadium described in the problem statement, such a system should be implemented first due to its low cost. If crowd flow issues persist, structural changes such as increased exit width[10] and added staircases[8] may be made. Simulations similar to this one may also be extended to incorporate additional parameters beyond exit speed, such as COVID-19 transmission and maximum crowd pressure. It may also be useful to incorporate additional aspects of the stadium environment such as the placement of concession stands. Computer simulations of crowd flow as analysis tools may also be applied to other stadiums, and additional solutions may be identified.

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