VARIABILITY OF BEHAVIOURAL PARAMETERS IN EGRESS SIMULATIONS OF STADIUMS

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ABSTRACT

Events hosted at stadiums attract large crowds, which requires an in-depth consideration of human behaviour to safely design and manage these structures. There is a growing demand to build new and revitalize current stadiums to a larger capacity to maximize revenue potential and minimize construction costs. However, there is little public data available to develop contemporary stadium guidance in order to optimize stadium performance and maintain an appropriate level of safety. This emphasizes the need for egress studies to provide validation for simulation models, since the reliability of these egress models in performance-based stadium design is dependent on the confidence of the input data. The research presented in this study describes novel data collection and subsequent egress modeling of an anonymous contemporary Canadian stadium to provide further insights to practitioners regarding the potential variability of behavioural parameters between experimental and simulated trials. In 2018, the case study stadium has had a documented fire while at low capacity. Interrogating safety and the stadium's egress performance at high capacity, two studies were carried out in which all events experienced crowds of over 20,000 people. High resolution cameras were strategically placed to capture crowds in the stadium stands and all egress routes. Various cases were observed: one event with all exits available and another with one primary exit closed, presenting a worse-case scenario with converging crowds. Pedestrian facial cues were observed to monitor a benchmark applied to stadium design that suggests people show signs of stress when total egress exceeds eight minutes. Additional data collected includes percentage distributions of people egressed over time and total post-game egress times which all exceeded 17 minutes. A scale stadium model was built to simulate the various cases using the MassMotion pedestrian movement modeling software and compared the pedestrian behaviour in the model to that of the experimental trials. Running various simulations allowed assessing sensitivity of the design according to parameters such as exit closures and varying demographics, all of which may impact human decision-making and walking speeds during an evacuation. Future work will include the addition of another Canadian stadium to the study, where a custom agent profile will be created in addition with further focus on qualitative behavioural aspects.

I. INTRODUCTION

In the context of construction over the next decade, it is known that the number of new stadium projects will be growing internationally despite forecasted recessions in some jurisdictions (Mills, 2017). The demand to build new stadiums and renovate current stadiums to a larger capacity is driven by the desire to maximize revenue potential collected from ticket sales. As the capacity of these structures increase, so does the importance of designing for efficient pedestrian flow to provide a safe and comfortable environment for occupants. Stadiums with poor pedestrian design can result in overcrowding and long queuing times, which is stressful for occupants and can result in potentially dangerous crowd sizes and densities. In stadium design, there are various 'minute' rules that are used for guidance in planning for pedestrian egress as outlined in Section II of this paper. Such guidance specifies finite durations in which all spectators should be able to exit from a specific area of the stadium under normal and emergency conditions. However, there is a lack of information as to where these benchmarks originated, what they were initially intended for, and how they should be interpreted in contemporary design. Based on such guidance, engineers may be restricted in being able to fully optimize the overall performance of stadiums, as prescriptive rules can result in neglecting consideration of certain aspects of human behaviour. One acceptance criterion for stadium architecture applied in many jurisdictions mandates that all occupants should be able to egress from a stadium in eight minutes (SGSA, 2007). The case behind this eight-minute rule applied to stadia lacks qualitative basis with only a brief explanation regarding a person's stress state in crowds. There is a shortage of publicly available pedestrian studies and corresponding movement data in order to design modern stadiums and prove compliance in modeled solutions. It is difficult to study the subject as most data sets remain proprietary in nature, often being performed to only be used internally within a specific project. The resources required to collect and analyze these data sets are also expensive and complex. There are also legal and privacy concerns regarding collecting these data sets and efforts to ensure ethics are obtained and maintained are very important. This resulting scarcity of information for stadia limits practitioners to the few original studies performed in the 1970s. The study herein is aimed to further investigate the context and applicability of these egress benchmarks being applied in an anonymous contemporary stadium design. The project's scope of work includes novel data collection at one contemporary stadium, with crowds of over 20,000, in order to provide confidence for simulated crowd models. These models allow assessment of the magnitude in which various parameters impact egress behaviour.

II. BACKGROUND

The eight-minute benchmark was first officially published in the 1972 SCICON report as the seven-minute rule stating that in durations longer than seven minutes the "pressures in the crowd becoming severe" and "movement through an exit becomes severe" (Poyner et al, 1972). This research was incorporated into The Green Guide, a manual used by professionals globally for the design and management of safety in sports stadiums. Examination of the rule from the 1973 first edition to the 2008 fifth edition of The Green Guide illustrates that today the guidance states: "The limit of eight minutes has been set as a result of research and experience, which suggests that within this period, spectators are less likely to become agitated, or experience frustration or stress..." (SGSA, 2007). It is important to note that this guideline pertains to normal egress and not to that of an emergency evacuation, which the Green Guide speaks to separately. Investigation into the underlying guidance reveals that it was formulated from photographing and videotaping the crowds during fifteen soccer matches at eleven different stadiums in the United Kingdom (Poyner et al, 1972). This research predates additional pedestrian studies such as those done in the 1970s by Jake Pauls, then of the National Research Council of Canada (NRC), however none of these studies appear to have been taken into consideration in the development of the eight minute benchmark. Beyond the brief and insufficiently detailed SCICON report, there is little public domain data to evaluate to develop contemporary stadium guidance. Although the Green Guide is used internationally, the guidance baseline followed in Canada, where this case study stadium is located, is the National Fire Protection Association Code 101 (NFPA 101) which contains documentation for means of egress for buildings and structures (NFPA 101B, 2018). Large stadiums are typically designed in accordance with the "smoke protected seating" provisions of NFPA 101, which requires that patrons can clear the seating area and reach an egress concourse in a certain amount of time. These permitted evacuation times are based on a linear relationship between number of seats and nominal flow time, with not less than 3.3 minutes for 2000 seats plus 1 second for every additional 50 seats up to 25,000. Beyond 25,000 total seats, the nominal flow time is limited to 11 minutes. Nominal flow time refers to the flow time for the most able group of patrons, as some groups less familiar with the premises or less able groups might take longer to pass a point in the egress system. NFPA also states maximum permitted travel distances to exits from the point in which the spectator has cleared the seating area and has reached an egress concourse, which dictates the overall evacuation time for the stadium.

III. FINANCIAL AND SAFETY CONSIDERATIONS

The incentive to construct arenas and stadiums on a larger-scale stems from the associated revenue potential of having more seats to increase ticket sales. For example, The Municipal Property Assessment Corporation (MPAC) has developed a guide on how it places a financial value on large sports stadiums in Ontario for taxation purposes. This provincial model aligns with how stadiums around the globe are most commonly valued; by the income capitalization approach in which it is assessed on the property's revenue earning power. This requires a detailed analysis of both income and expenditures, both for the stadium's valuation being determined and for other comparable venues that have already been operating to use as a benchmark valuation. Aside from space rental leases and concession revenues, the number of ticket sales for regular and luxury seats are a significant revenue generator for stadiums (MPAC, 2016). Although incorporating a higher number of seats increases initial investment, it does not significantly increase yearly operational expenses which makes building stadiums to a larger capacity an attractive investment for municipalities and stadium managers from a long-term perspective. The financial incentive to design stadiums to a larger capacity makes egress and evacuation planning extremely important so these highly-populated structures can operate efficiently and safely. A well-planned pedestrian design also makes the building easier to operate from an event management and security perspective.

Furthermore, recent stadium emergencies have demonstrated that there is a need to put occupant safety at the forefront of stadium design. In 2017, a bombing at a stadium in Manchester, UK resulted in 22 casualties and over 100 injuries (Lizzie, 2018). The onset of mass egress caused particular difficulty with regards to evacuating the wounded from the grounds. Additionally, the stadium which is reviewed by the study herein was subject to a fire in 2018 after some spectators set off flares in the stands. Preliminary review of this incident reveals some interesting behaviour in which those individuals that caused the fire did not appear to feel the need to evacuate the area despite the flames having visible potential to spread. Group behaviour was also apparent where those not affiliated to the flares immediately distanced themselves from those associated to the flares and proceeded to egress. Moreover, crowd crush accidents can result from unsafe stadium designs or poor operational management. In 1989, ninety-six individuals, ranging in age from 10 to 67, lost their lives at a stadium in Sheffield, England due to insufficient stadium capacity and poor management decisions (Bilefsky, 2017). Delivering crowd safety should begin in the design phase and adopt an approach that integrates design and management (Rowe and Ancliffe, 2008). It is beyond the scope to provide a literary review of stadium disasters other than to specify that it is a credible concern. Although the study herein does not analyze egress in the context of an emergency due to obvious ethical concerns, it is important to understand that normal egress performance is a baseline indicator of how efficient the stadium will perform in an evacuation.

IV. EXPERIMENTAL STUDY

This study herein considered two egress trials with crowds of over 20,000 people, carried out at a contemporary Canadian stadium. The stadium, originally constructed in the 1960s, was renovated with modern upgrades in 2014 which involved revitalization of the existing north stands and construction of new south stands. This stadium has a total capacity of 24,000 people, with space for an additional set of 12,000 temporary stands which are erected during special events. Trials observed took place in the fall where the stadium seating stands were open to the environment, while most of the egress routes were roofed and enclosed on two sides. High resolution cameras were strategically placed to observe crowd conditions in the stands, egress paths, and were able to capture facial expressions of pedestrians. The cameras used include a Canon EOS 5DS (50.6 megapixels), Canon EOS 5D Mark III (22.3 megapixels), and two Canon Rebel T6 cameras (18 megapixels). Filming was done in accordance with directions provided by the stadium and event managers. This study considered factors with potential to influence behaviour including the game score, weather, and demographics by performing multiple trials at the same stadium.

Trial One

The first trial was carried out during a North American football event at 92% capacity. As seen in Figures 1 and 2, cameras were distributed over the stadium's three available exit points. Cameras were also positioned to capture the stands, including the egress routes which spectators took to reach the exit from their seat. Heavy rainfall and winds occurred during the entire egress duration.

Figure 1: Gate One (Red Arrow) and North Walkway (Blue Arrow)

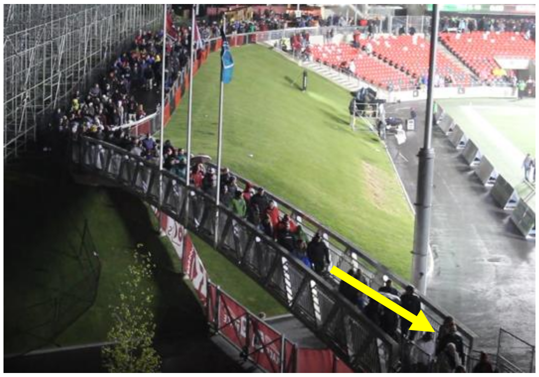


Figure 2: East Bridge (Yellow Arrow) Exit

Trial Two

The second major trial was carried out at the same contemporary stadium, during a similar game at 97% capacity. The East Bridge was closed for ingress and egress, because the surrounding area was under construction to erect the temporary stands which would be used for an upcoming major event to expand the stadium capacity temporarily. This exit closure permitted spectators to egress through only the two other exits: Gate One and the North Walkway. This trial presented an effective worse-case scenario due to the exit closure, as stadium egress requirements must still be achieved in such events. The game score was extremely close until the last second potentially increasing the level of commitment from spectators to stay to the end. In contrast to the first trial, the skies were clear and no rain occurred throughout the event.

V. EXPERIMENTAL RESULTS

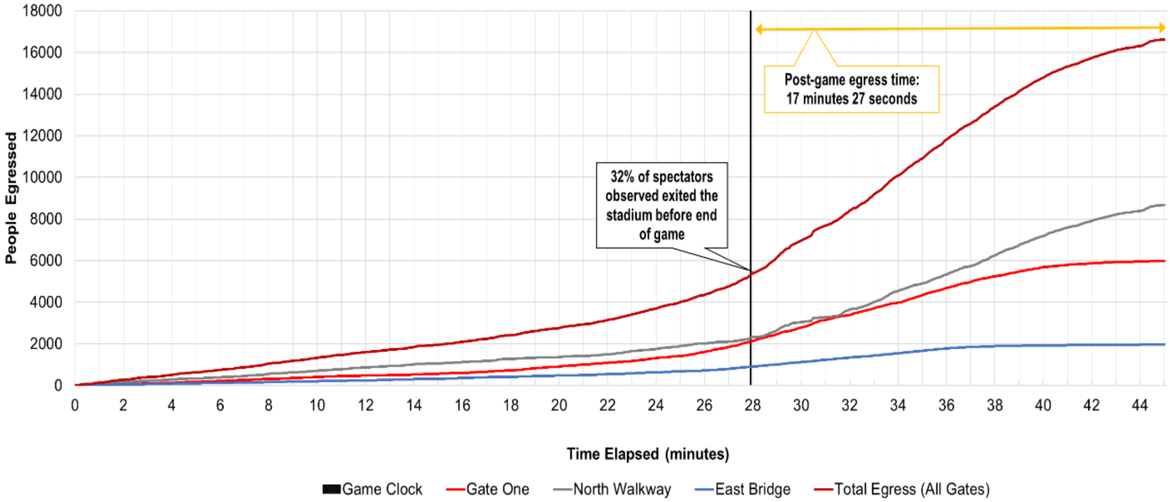
Table 1 summarizes the attendance numbers and egress times of the two main trials. The 'Egress Time After Game Buzzer' can be defined as the total duration in which people were egressing starting, from the end of the game buzzer to when the last person exited the stadium. This differs from the Total Egress Time which also includes the duration in which spectators began to exit the stadium before the end of the game. The criteria used to identify the onset of the Total Egress Time was the point in time in which 100 occupants had left the stadium over a period of three minutes. This measure is arbitrary but was applied to both experimental trials.

TABLE 1: INGRESS AND EGRESS RESULTS FROM TWO TRIALS

Event	Total Attendance	Total Capacity	% Capacity Used	Total Ingress Time	Total Egress Time	Egress Time After Game Buzzer	Notable Game Factor
Trial One	21,965	24, 000	92%	1 hr. 16 min. 13 sec.	45 min. 24 sec.	17 min. 27 sec.	Heavy rainfall
Trial Two	23, 280	24, 000	97%	1 hr. 34 min. 12 sec.	86 min. 32 sec.	33 min. 35 sec.	One main exit closed, close game score

With the closure of the East Bridge in Trial Two, the egress time was extended by 91% compared to that of the first trial. This has major implications in terms of the stadium performance in an evacuation setting if an exit were to be closed, as normal egress performance can be a strong indicator of performance in an evacuation. Inherent risk exists for an emergency situation under these limited gate scenarios as the required safe egress time (RSET) is significantly increased. The exit closure also caused an increase in crowd density when compared to the Trial One event footage. A Canon EF 70-200 mm (F/2.8L IS II USM) zoom lens was used to observe the crowd behaviour in the denser areas and walkways to search for signs of agitation, frustration, or stress. The term stress can be defined as an individual's somatic response to an event or environment, which may appear in the form of physical or psychological symptoms (Innes, 1984). Physical responses could include facial cues of being concerned, worried, or upset and more noticeable behaviours such as pushing and shoving. However, there are limitations to recognizing stress on film as it could also manifest itself in a less apparent form such as through headaches, anxiety, or depression. In the two experimental trials, observed behaviours did not indicate the crowd is under stress, despite the spectators being subject to crowded areas for longer than eight minutes. Observed queues were moving and not stationary, and occupants had visibility to the exit and thus the source of any queues that did occur. These sight lines to the exits may have aided in reducing any potential frustration in spectators as any delays would have been known to the pedestrian.

Approximately one third of spectators that used the filmed exit gates had left before the game's end, a trend which was observed in all trials as depicted in Figures 3 and 4. In Trial One, the researchers attributed this behaviour to the inclement weather, which many spectators appearing to leave the premise prior to the game ending to escape the storm. However, this behaviour seemed to occur independent of all factors such as game importance and score, as Trial Two was one of the final season games. The close game score in Trial Two did result in a large crowd gathered to watch the final minutes of the game on the overhead screen at Gate One in attempt to avoid the post-game crowds during egress. This crowd led to an immediate and significant increase in flowrate through the exits upon final game buzzer. Note that the total number of people egressed in these graphs were based on the footage captured only and discrepancies between these values and the total number of attendees listed in Table 1 exist. These differences can be attributed to the fact that the spectators that left before the aforementioned criteria used to identify the onset of Total Egress tracking (100 occupants over 3 minutes) were not filmed or considered in the study. Additionally, spectators that stayed to attend the post-game activities on the field were also not considered in the study but will be included in future work.



. Figure 3: Trial One Egress Over Time

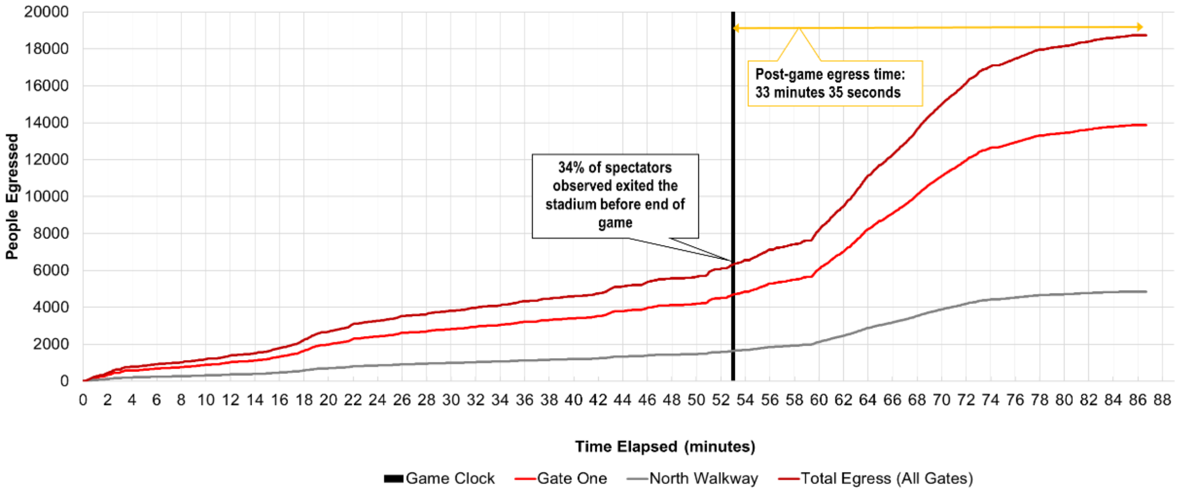


Figure 4: Trial Two Egress Over Time

Next, the gate utilization for impact and egress for each event was reviewed and summarized in Figure 5. The percentage of people that used a specific entrance for ingress aligned within 5% to those that egressed through that exit. This attests to the commonly known philosophy that people tend to leave a building the same way they entered, even if the route is a less efficient alternative. Such behaviour manifests itself in people as studies show that individuals prefer the known over the unknown (Sime et al., 1988). This emphasizes the importance of familiarity with exit routes or the application of signage to promote their usage. Furthermore, it was observed that upon closure of the East Bridge, approximately 75% of spectators chose to egress through Gate One, which is over double the utilization when compared to the utilization of Gate One in Trial One. It would have been logical to predict that the North Walkway would have been the alternate route of choice for those originally intending to use the East Bridge since these exits lead out to the same side of the stadium and thus the same facilities such as parking locations. This implies there are other factors at play behind spectator's egress route choice, such as the reluctance to queue upon exiting as the North Walkway was subject to standstills and reduced flowrates after the game. Spectators migrated towards the wider exit, Gate One, which provided approximately quadruple the exit-width capacity and therefore reduced potential for bottlenecking.

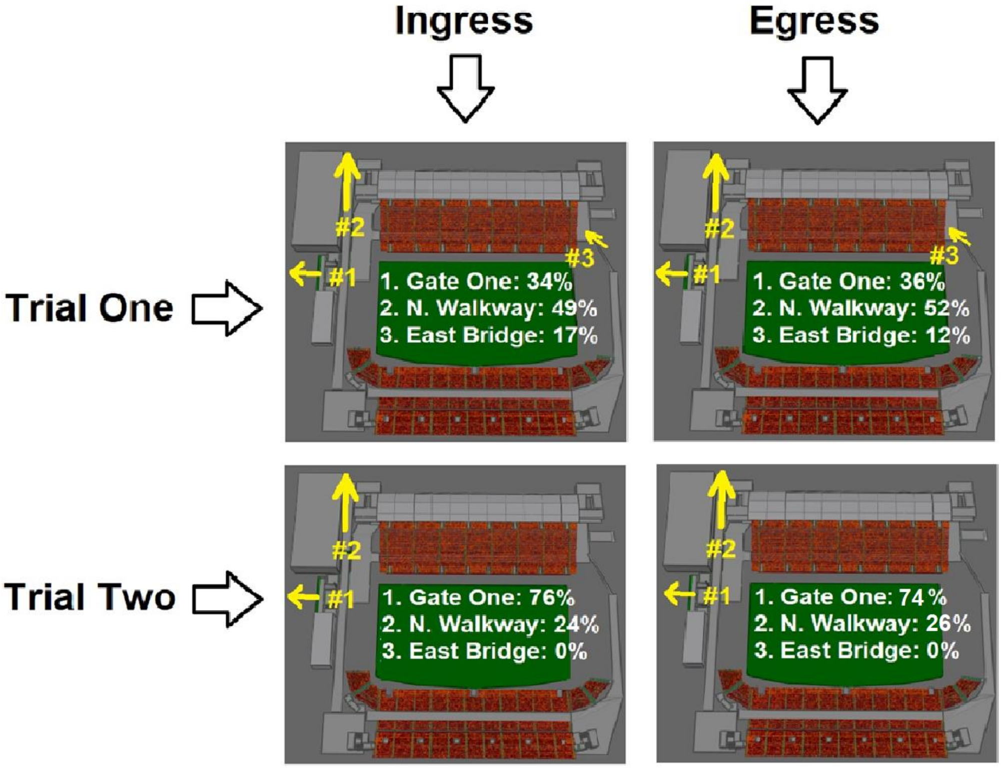


Figure 5: Gate Distribution Used for Trials One and Two (Gate One, North Walkway, East Bridge)

VI. STADIUM MODELING

A scale drawing of the stadium was created based on measurements and reference geometry gathered via on-site surveying and from Google Earth software. This stadium drawing was then imported into the MassMotion evacuation modeling software in order to run validation scenarios which were then followed by preliminary predictive egress simulations (Kinsey, 2015). The validation runs were calibrated to the experimental trials and the predictive scenarios modeled varying demographic distributions and gate configurations.

Agent Profiles Developed

Within MassMotion all agents are assigned a preferred walker speed, representing the maximum speed an agent will walk during a simulation. The agent speeds can move slower then their preferred walker speed due to local crowd density, agent deceleration and the adapted social forces model which is used to simulate avoiding collisions with other agents. The default agent size is 0.5 m in width for all agents. Agents select which route to use during a simulation based on the route they expect to reach their target destination in the shortest time through use of a route cost utility function.

All scenarios were first simulated using the default agent profile for MassMotion, the Fruin Commuter, which is based on the data collected by John Fruin (Fruin, 1971). This profile is based on speed and density data collected in the New York city subway in the 1970s for commuters during general circulation. The main limitation with the Fruin profile is that it does not have an available demographic breakdown, but rather applies a nominal distribution of a single walker speed, which is used to randomly assign a speed for all agents. For this reason, the modeler developed tailored agent profiles to more accurately represent the demographics observed during the stadium trials. Four agent speed profiles were created in order to characterize the behaviour of children, young adults, adults, and elderly. The average walking speeds used were referenced from the findings of studies carried out by K. Ando, which provides a mean and range of speeds for children (<18 years old), young adults (19-36 years old), adults (37- 65 years old), and elderly (>65 years old). The minimum and maximum walking speeds used in these ranges were 0.6 to 1.7 meters per second (Ando et al., 1988). Customized walking speed development is underway by the author using their own experimental data, but analysis is premature for this paper's publication. For the illustrative purposes of this study, the Ando speeds will be applied as they represent a sizable deviation in speed from young to old. The profiles of disabled individuals are not considered, as accessibility of the stadium is studied in future work by the authors and a profile for disabled patrons will be developed. Footage taken by the author's cameras during the events was analyzed and a 20% sample size of the spectators were reviewed to determine the demographics of the events. The age distribution was found to be 6% children, 29% young adults, 53% adults, and 12% elderly. It should be noted that in other sporting events these demographics can vary and should not uniformly be extended to all sports events. These demographics were used in MassMotion to forecast the events observed in the trials in order to validate the model.

Agent Pre-Movement Times

A situation specific set of pre-movement times was defined by reviewing the footage. Of the spectators still seated when the final game buzzer sounded, it was found that people began to exit from the range of five seconds to one minute ten seconds. All premovement times observed are outlined in Table 2. Spectators that had no intention of egressing and remained in their seats for postgame activities on premise were not assigned a pre-movement time. These pre-movement times were modeled in MassMotion as a normal distribution. The calculated weighted average of the data set was found to be 36 seconds, which aligns with the behaviour observed in the footage as the majority of people moved around this time frame. The standard deviation of the data calculated and used in MassMotion was 19 seconds.

TABLE 2: OBSERVED PRE-MOVEMENT TIMES

Percent of Spectators that had started Egress	**Time (s)**
Minimum	5
10%	10
30%	17
50%	26
70%	38
90%	57
Maximum	70

Validation and Verification Simulations

As outlined in Table 3, two different validation scenarios were simulated using MassMotion. Each simulation was modeled using both default Fruin Commuter speeds as a benchmark and speeds observed from the Ando studies in order to test various demographic distributions for children, young adults, adults, and elderly. Simulation one was calibrated to represent Trial One with all exits open, applied the observed demographic distribution, and populated with the actual number of spectators still seated at the final game buzzer. Simulation two was calibrated to represent Trial Two with the East Bridge closed, applied the observed demographic distribution, and populated with the actual number of spectators still seated at the final game buzzer. Simulation one and two results were compared against the observed trials to validate the model, which was necessary before using the model for further simulation applications.

TABLE 3: SUMMARY OF MASSMOTION MODEL VALIDATION SIMULATIONS

Simulation Number	Agent Speeds Applied	Demographics	Population Count	Exits Open or Closed
1a	Fruin	n/a	Trial One event actual number of spectators left in stadium at final game buzzer	All open
1b	Ando	As observed at events: 6% children, 29% young adult, 53% adult, 12% elderly	Trial One event actual number of spectators left in stadium at final game buzzer	All open
2a	Fruin	n/a	Trial Two event actual number of spectators left in stadium at final game buzzer	East bridge closed
2b	Ando	As observed at events: 6% children, 29% young adult, 53% adult, 12% elderly	Trial Two event actual number of spectators left in stadium at final game buzzer	East bridge closed

First, qualitative comparison between the simulations and the footage from Trials One and Two was done to ensure alignment in terms of agent density levels and egress route utilization. For example, the author compared the usage of Gate One and the North Walkway in the simulation as illustrated in Figure 6 to that in Trial One as depicted in Figure 1. It was verified that the same points in the stadium architecture were subject to congestion. Analysis results shown below were simulated allowing the agents to select their preferred exit instead of assigning agents exits based on the collected data. This resulted in a different distribution of gate utilization by agents compared to the experimental trials. These results will be outlined in future work, however it is important to note that average total egress times did not differentiate between the two exit assignment methods, despite the gate usage varying significantly.

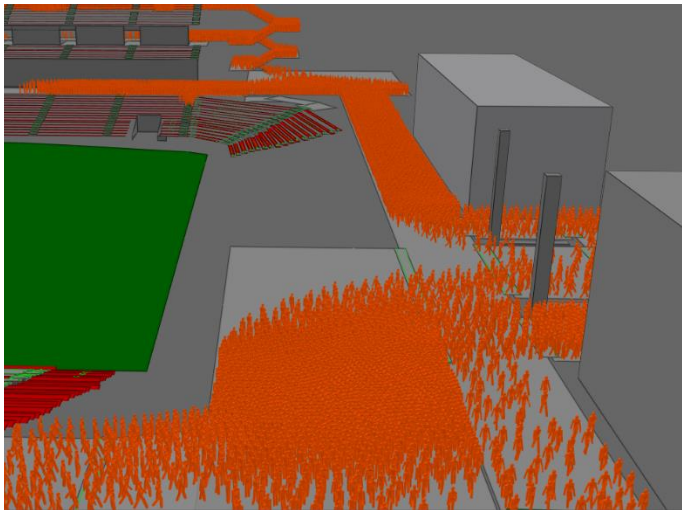


Figure 6: MassMotion Simulation During Egress at Gate One and North Walkway

Next, quantitative analysis of the stadium model was carried out. Figure 7 and Figure 8 represent the population count of the model stadium over time for Trial One and Trial Two respectively. Comparing the simulated total post-game egress times to that of the observed trials in Figures 3 and 4, it can be noted that the model egress times align within 40 seconds for Trial One and four minutes 50 seconds for Trial Two. These times are within reasonable range to consider the model calibration representative of the trials, however it is evident there are other influencing factors at play which account for the degree of variability.

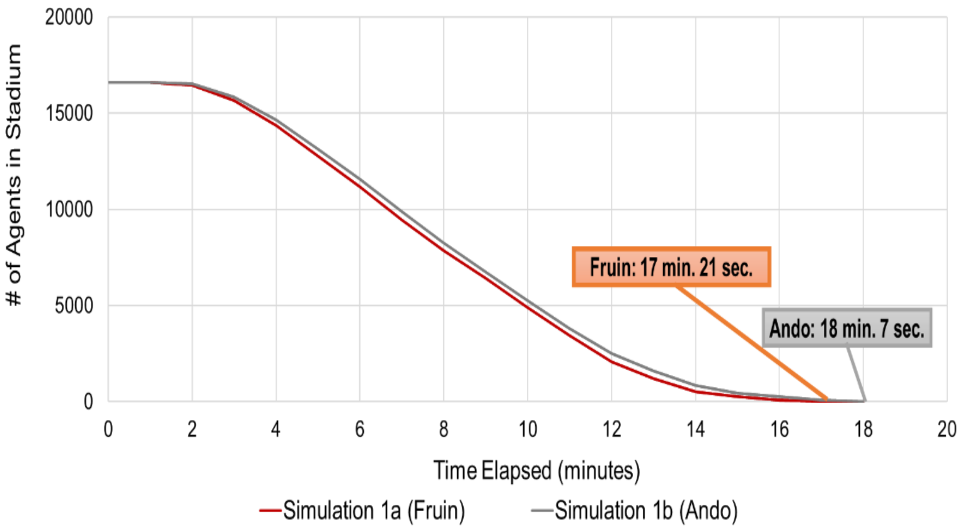


Figure 7: Population of Stadium During Trial One Egress (Simulations 1a and 1b)

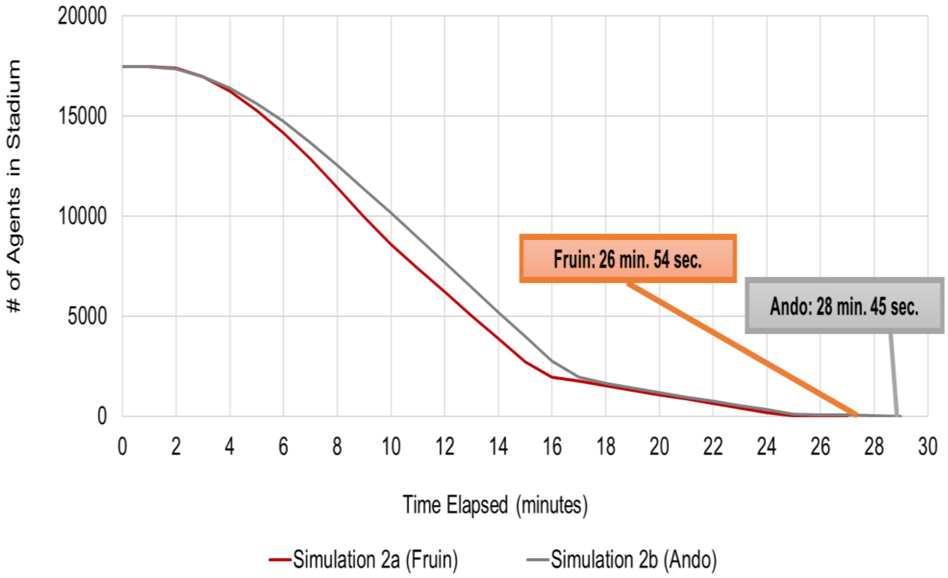


Figure 8: Population of Stadium During Trial Two Egress (Simulations 2a and 2b)

One aspect of the sports event that was not captured in the simulation is the concept that people commonly attend sporting events in groups. In general, it is known that walking speeds decrease linearly as group size increases (Moussaid et al., 2010). Therefore, group behaviour tends to increase overall egress times. Furthermore, the presence of vendors and post-game activities on the field encourages spectators to spend time inside the stadium after the event, making egress not their immediate priority. In contrast, each spectator in the model had evacuating the stadium as their primary task, ultimately reducing the total time required to vacate the grounds.

Predictive Simulations

After model validation, the simulations summarized in Table 4 were run with the objective of testing the egress performance of the stadium at full capacity and the impact of varying demographic distributions in attendance. Simulation three tested the stadium with all exits open at three various demographic distributions: the actual demographics observed at the event, one trial with the majority of spectators as youth, and one trial with the majority of spectators as elderly. Simulation four tested the same three demographic distributions as simulation three, but with the East Bridge closed.

TABLE 4: SUMMARY OF PREDICTIVE MASSMOTION SCENARIOS TESTED AT FULL STADIUM CAPACITY

	Simulation Number	Agent Speeds Applied	Demographics	Population Count	Exits Open or Closed
Testing at full capacity	3a	Fruin	n/a	At full capacity	All open
	3b	Ando	As observed at events: 6% children, 29% young adult, 53% adult, 12% elderly	At full capacity	All open
	3c	Ando	Higher distribution of young people: 30% children, 45% young adult, 20% adult, 5% elderly	At full capacity	All open
	3d	Ando	Higher distribution of elderly: 5% children, 20% young adult, 30% adult, 45% elderly	At full capacity	All open
Testing impact of one main exit closure at full capacity	4a	Fruin	n/a	At full capacity	East Bridge closed
	4b	Ando	As observed at events: 6% children, 29% young adult, 53% adult, 12% elderly	At full capacity	East Bridge closed
	4c	Ando	Higher distribution of young people: 30% children, 45% young adult, 20% adult, 5% elderly	At full capacity	East Bridge closed
	4d	Ando	Higher distribution of elderly: 5% Children, 20% Young Adult, 30% Adult, 45% Elderly	At full Capacity	East Bridge closed

As illustrated in Figures 9 and 10, the egress times of the stadium model at full capacity require a minimum of 21 minutes 14 seconds, which was exhibited in Scenario 3a. These results suggest evacuation within the eight-minute guidance benchmark could be challenging to achieve in this given anonymous stadium design. As aforementioned, this stadium often erects temporary stands providing an additional 12,000 seats for a total of 36,000 seats. This set-up represents an increase of 50% in terms of capacity which would only further magnify the difference between the realized egress times and eight minutes. This scenario will be considered in future work but is beyond the project scope at the time of writing. Additional analysis of travel distance limitations and emergency exit use is currently under evaluation by the authors.

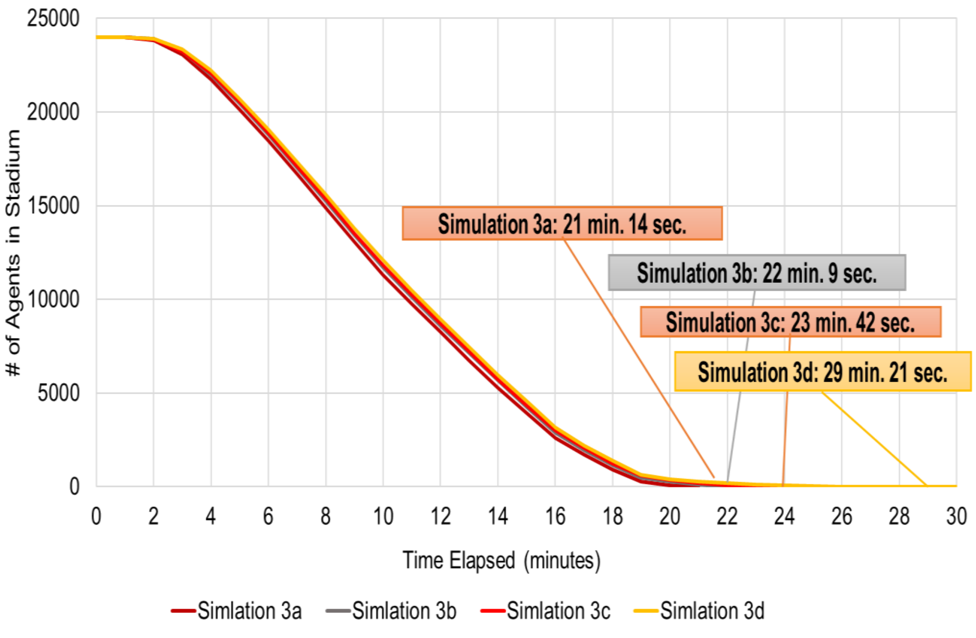


Figure 9: Population of Stadium Over Time (Simulations 3a, 3b, 3c, and 3d)

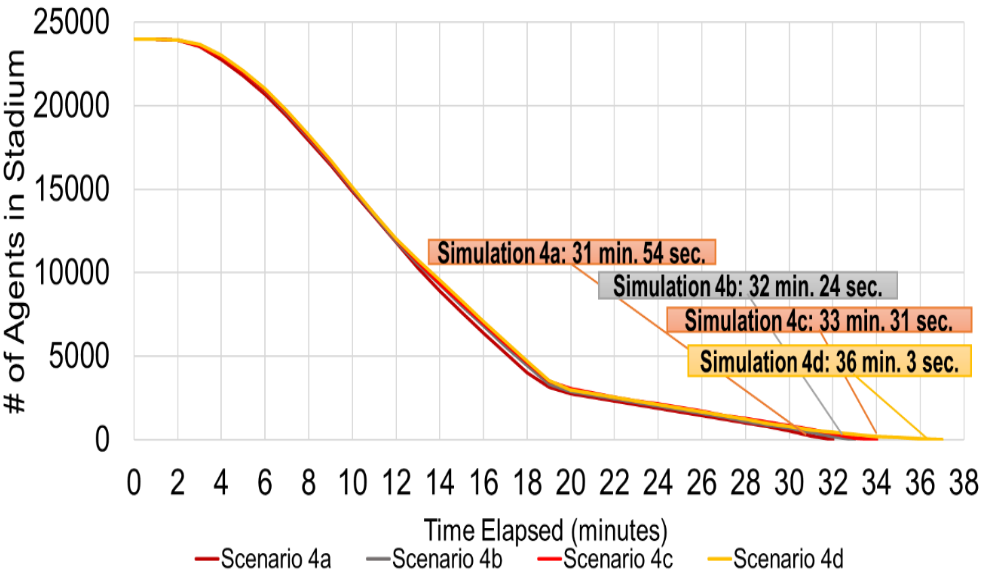


Figure 10: Population of Stadium Over Time (Simulations 4a, 4b, 4c, and 4d)

Furthermore, the simulations with a higher composition of elderly (3d, 4d) increased total egress times by a range of four to seven minutes. The simulations with a higher composition of children also experienced total egress times approximately one minute longer than that of the demographics observed at the real trials, which is governed by the children's walking speeds that are slightly slower than your average young adult. When it comes to designing stadiums, knowing their intended use including the types of events that will be hosted and what demographics those events may attract are important considerations for egress planning.

All the simulations in this case study were run three times and averaged to find the mean total egress time for the given scenario. These findings showed deviations ranging from one to four minutes for the simulations. Future work will include more runs and a complete statistically significant set of simulations to ensure convergence of average egress times. The simulations herein indicate that demographics play a role in overall egress times, but congestion is the governing factor for this stadium. In other words, an increase of 10% in the walking speeds of agents in a simulation did not directly translate to an increase of that magnitude in terms of total egress time in the simulation. This was a trend discovered in all simulations run, concluding that congestion had the largest impact on egress times for this case study.

VII. PRELIMINARY CONCLUSIONS AND FUTURE WORK

General conclusions are limited to this stadium only. The basis of the design benchmark that states spectators become agitated in crowds after eight minutes originates from the SCICON research. Subsequent editions of the Green Guide have been issued since 1973, with little update to the context of this guidance. Evidently, the total egress times for the stadium studies carried out by researchers in observed trials and modeling are all well in excess of 8 minutes. The egress observed was not of a high stress state as most patrons were visibly seen to be laughing and smiling upon queuing and exiting by field cameras. To examine stress states accurately though at all stages of egress, it is recommended that a survey approach be employed in a future study in addition to monitoring other metrics. The author's study ethical permissions in this case did not allow to assess these metrics through surveying. Ultimately, a follow on study can work towards the creation of contemporary bench marks to optimize stadium design in this regard. Although this was not an emergency situation, it should be noted that normal egress performance of a stadium is a baseline indicator for egress performance during an evacuation. Modeling various demographic distributions did not govern egress times for this stadium. In other words an increase in walking speeds did not result in a proportional decrease in egress times, indicating the architecture was the governing factor for this stadium. The limitations in this research include modeling this stadium for the additional 12,000 stands erected during temporary events which will be included in future work. Future research will be built on the findings of the work and aim to help practitioners establish contemporary design guidance for stadium egress. Three additional trials were being carried out at another Canadian stadium at the time of this publication, in which qualitative behavioural aspects will be the focus of analysis. The researchers will use the behaviours uncovered to ensure their impact is being considered in the MassMotion software in order to accurately represent stadium egress. Additionally, outside influences that may impact the ability to exit will be assessed in future work. For example, Gate One of the stadium studied in this paper leads out to a main road, therefore impediment of this road may hinder ability to egress. Ultimately, the modeling techniques developed will lead to a baseline performance which can be considered for fire safety.

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