Crowd Behaviour in Canadian Football Stadia - Part 1- Data Collection

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Abstract

Large crowd sizes at stadia events require an in-depth consideration of human behaviour, since the reliability of egress models in design depends on the confidence of the input data. However, there is little contemporary public data surrounding crowd behaviour, and its implementation into pedestrian movement models, particularly focused on Canadian demographics in stadia. A novel data collection (Part 1) and subsequent egress validation modelling of a Canadian stadium were completed to examine the variability of simulations with behavioural inputs (Part 2). The demographic distribution, pedestrian speed, exit and route choice, and areas of congestion were quantified using high resolution cameras. Behaviourally, pedestrians exited the stadium where they entered which created high levels of cross flow. It was observed that contemporary walking speed profiles for stadia will differentiate from classical profiles especially with reflection of demographic distribution by as much as 31%. Individual walking speeds, while highly variable, impacted overall egress time. Crowd density also being a factor that further reduced their speed.

Key words: Egress, Movement speeds, Data collection, Stadium design, Crowd behaviour, Exit choice

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1. Introduction and Objectives

There is a constant demand to build new stadia and renovate current Canadian football stadia to a larger capacity. By doing so, special events can be planned, and ticket sales can be maximized. As the capacity of these structures increases, so does the importance of designing for efficient pedestrian flow to provide a safe and comfortable environment for occupants. Calculations where applicable for design require the input of accurate behavioural characteristics of decision making in way finding (such as exit choice) and renewed movement profiles (Kuligowski et al. 2017; Ronchi et al. 2019). However, there is a lack of understanding and implementation of the behaviours exhibited by individuals when modelling the egress process. In creating movement simulations, a common approach is to use default inputs of exit and route choice in models rather than to use real observed behaviours (Gwynne and Hunt 2018; Kinsey et al. 2020). If default inputs are used, agents commonly select their route based on the route they expect to reach their target destination in the shortest time through the use of a route cost utility function (lowest cost path). In reality, individuals consider a variety of factors which may influence a person's route choice, including their familiarity with the route. Furthermore, existing movement profiles such as the Fruin profile are often used. This popular dataset is based on speed and density data collected in the New York City subway in the 1970s for commuters during general circulation. The main limitations with the Fruin profile are that it is outdated, and 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 (Fruin 1971).

However, if new data regarding behaviours is collected, it will often only be used internally for a specific project. It is difficult to collect data such as behaviours (exit and route choice) and movement (walking speeds) as the resources required to collect and analyze this information can be expensive. There are legal and ethical concerns regarding collecting these data sets. These restrictions result in a scarcity of publicly available information for stadia, specifically surrounding movement and behaviours.

Herein, we aim to address these above knowledge gaps by presenting novel data that is collected from circulation (ingress/egress) trials at a contemporary Canadian stadium. The study is focused on Canadian demographics and stadium architecture. Insights herein will allow for future comparison with data from other countries.

Three events were filmed for analysis to understand how individuals' behaviour affects the egress of the entire population in a Canadian Football Stadium. This study will be useful to researchers as they can use the methods presented to create other movement profiles for demographics, populations or situations not considered in this project (for example, group movement, those with disabilities, or the current implications of social distancing). Furthermore, practitioners will find value in this study as it will allow them to better design stadia by understanding the behaviours exhibited when egressing.

2. Canadian Studies and Resources

Design guidance followed in Canada, where this case study stadium is located, is the National Fire Protection Association Code 101 (NFPA 101) which contains requirements for means of egress for buildings and structures (NFPA 2002). Canada does not follow the European designed “Green Guide” for pedestrian movement (Sports Ground Safety Authority 2007). There is a dearth of contemporary information available where a practitioner may wish to perform a computational design. This is despite Canada having a history of evaluation of pedestrian movement in stadia. Foundational research was conducted by Jake Pauls in the 1970s and 1980s in attempt to contemporize design procedure (Pauls and Johnson 1977; Pauls 1979; Pauls 1980; Pauls 1982). Pauls performed three major human behaviour studies on Canadian stadia which included the Olympic Park in Montreal, the Commonwealth Stadium in Edmonton, and the Exhibition Stadium in Toronto. Movement and behaviours were filmed during these studies using stereoscope cameras. In the Montreal study performed in 1976, Pauls observed many behaviours including movement and crowd flow, the use of doors, ramps, stairs and handrails, as well as the effects of signage. The focus of the study was to provide insight on concerns regarding building design and operations. Overall, the study concluded that the poor design of the stadium led to hazardous situations (Pauls and Johnson 1977). The second study led by Pauls was performed in 1979 in the Commonwealth Stadium in Edmonton, and focused specifically on the movement of individual people on stairs (Pauls 1979; Pauls 1980). The study filmed stairs that varied in width and features such as handrails, and found that many preferred to use handrails as it made them feel safer and more comfortable. Pauls also used the recordings to quantify the extent of body sway, the natural tendency of people to oscillate side to side as they move and determined that stair widths must account for this body sway. The third study led by Pauls was performed on July 16, 1980 at the Rock Concert in the Exhibition Stadium (Pauls 1982). This study aimed to observe crowd conditions and was recorded through filming, photographs, audio recordings and written records. Pauls discovered security had difficulty controlling the crowds on the field as the event progressed; many would move from the stands to the field. For several hours, the crowd directly in front of the stage was so dense, people were unable to move and needed to be pulled up and out of the crowd from the stage in order to exit. This is noted as a major hazard which could lead to a crowd crush. Pauls continues to list suggestions to prevent hazards from occurring again in the future, including properly illuminating egress paths and controlling the number of people who are entering the field. While Pauls’ data has been vital to Canada’s creation of guidelines and understanding of human behaviour in stadia, his studies occurred several decades ago, and are therefore no longer representative of Canada’s current demographic distribution and their behaviours such as their fitness. These reasons are partly why researchers have advised against using the data collected from studies performed during the 1950s to 1970s (Pauls 1982). It is noted that Fruin, along with other authors of earlier datasets have requested that their data not be included in more recent versions of the SFPE handbook, potentially to avoid being used in engineering calculations (Society of Fire Protection Engineering, 2016).

A recent Canadian stadium study (Young et al. 2021) was completed by the authors’ research team regarding egress primarily in a tennis venue under various conditions (normal egress, high-motivation egress, and emergencies). That study filmed and analyzed trials for each egress stimuli while also providing readership with a holistic literary review and future research needs for stadia research. Route choice, density and understanding pedestrian decisions were the focus of data collection. The study found that egress behaviours varied with the type of event and that the overall egress movement is influenced by said behaviours. The study was limited as it did not focus on representative crowd sizes (<2000 people were monitored in each analysis) seen in larger Canadian stadia where modelling may be needed to assess the design. Subsequently, movement speeds and modelling were not performed in that study. International data collection and subsequent previous modelling efforts are briefly reviewed in Part 2. This study herein aims to address the need for a better understanding and quantification of egress behaviour in larger Canadian stadia that may be used in a computational approach.

There is a clear need for further research internationally and this is supported by the Society of Fire Protection Engineers (SFPE) who have created a Research Roadmap which states the main research priorities for Fire Safety Engineering. Under the human behaviour category, the Research Roadmap states that the main research priority for data collection is demographics, specifically cultural differences in demographics (SFPE 2018). The SFPE also states that under the Risk and Probabilistic approaches, large populations are the second greatest priority. This study herein aims to address these knowledge gaps by studying a Canadian Football Stadium. Collecting movement speeds and then later validating them with models will form the basis of a series of other infrastructure types and a range of emergency stimuli such as fire drawing upon this work.

3. Data Collection Procedure

This study herein considered three egress trials carried out at a contemporary Canadian stadium predominately used for Canadian Football. Observation and filming took place in the autumn where the stadium seating stands were open to the environment. Most of the egress routes were not roofed nor enclosed but open to weather elements.

3.1 Preliminary Trials

Prior to filming the main trials presented herein, several preliminary trials were performed. The preliminary trials were primarily conducted to optimize camera number and performance (maximum vantage view for observing exits for example). Demographics-based movement speeds were also generated from the final preliminary trial. The three exit locations (Gate One, the North Walkway, and the East Bridge) can be seen in Figure 1. All filming was done in accordance with directions provided by the stadium and event managers, and the authors were restricted to filming the South Stands and all exit gates.

The final locations and the area the cameras were able to capture can be seen in Figure 1. 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). Two students were placed at each location, two were rotating between them, and one supervisor was present. Because the cameras were publicly accessible, a pair system was implemented to ensure the personal safety of the students. The camera view (noted as 2' in Figure 1) was positioned to capture the South Stands in the last preliminary trial with the objective of documenting walking speeds in the stadium. Through this view on Camera 2', single-directional movement could be observed with certainty, which allowed for the derivation of walking speeds on both stairs and flat surfaces during egress. This was unlike the bi-directional flow the authors have called the crossflow effect, which was observed as spectators tried to exit through Gate One and the North Walkway in the main trials. The authors were allowed to place camera 2' at its optimal position for the preliminary trials, but during the main trials, this was not allowed as it occupied walkways and seats. Subsequently, the camera was moved to location 2 for the main trials, located in the landings of the North Stands of the stadium, out of the visibility of the participants. Other cameras were positioned to record the number of people using each exit, and which exit people would choose to use based on which overall area they came from. This was then used to infer where (i.e. in which stand) they were sitting and generate rough origin-destination data. This origin-destination data combined with the movement speeds were then used for pedestrian modelling, which is outside the scope of this paper but will be discussed further in a future article.

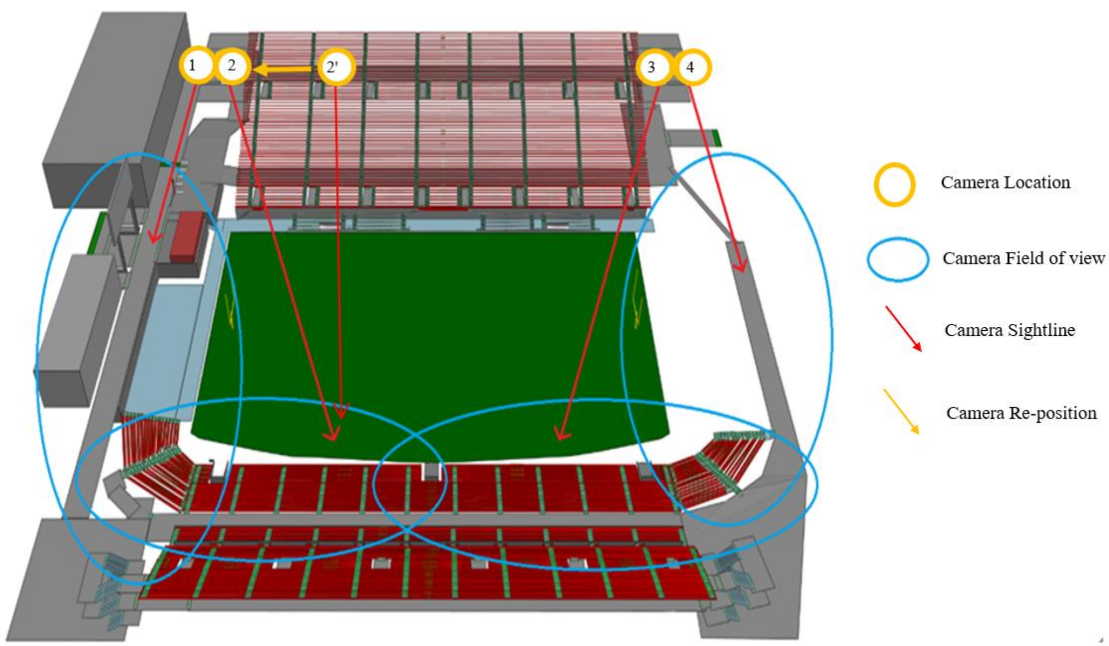

Figure 1. Exit Locations and Final camera sightline positions (Note Camera Position 2' changed in final preliminary to Camera Position 2 in main trials)

3.2 Trial One

Following the final preliminary trial which optimized positioning and camera number and derived a movement profile, the first trial was completed during a Canadian football event at 92% initial capacity. Cameras were distributed over the stadium's three available exit points. Rainfall and winds occurred during the entire egress duration.

3.3 Trial Two

The second major trial was carried out at 97% initial capacity. In contrast to the first trial, the skies were clear. However, the East Bridge was closed for ingress and egress because the surrounding area was under construction to erect the temporary stands. These would be used for an upcoming major event to expand the stadium capacity temporarily. This exit closure permitted spectators to egress through the two other exits: Gate One and the North Walkway. This trial presented an effective worst-case scenario due to the exit closure as stadium egress requirements must still be achieved in such events. While the original cameras and their locations remained the same, a fifth camera, the Nikon D 3300 (24.2 megapixels), was added. This camera was positioned to film the crossflow effect observed in the first trial. When examining the cross flow, the camera position was also able to record the effect of the game score. At the end of this trial, the game score remained close. This increased the level of commitment from spectators to stay to the end. The effects of the game score are used to understand the impact of behavioural effects on egress movement.

4. Data Collection Results and Discussion

During Trials One and Two, attendance, demographic distribution, egress times and exit choice were measured or analyzed from the recordings. Table 1 summarizes the attendance numbers and egress times of the two main trials. Herein, we consider underlying information which will be critical to collect from videos when considering the overall validation approach to the pedestrian modelling. These include pedestrian demographics and movement speed (with density) as well as exit flow, choice and density. These aspects also inherently include information regarding the occupant's behaviour and decision making upon egress.

Table 1. Egress Results from Two Main Trials

Event	Total Initial Attendance	Total Attendance at start of egress	Total Capacity	% Capacity Used (initial/start of egress)	Total Egress Time	Egress Time After End of Game
Trial One	21, 965	16, 619	24, 000	92/ 75	45 min. 24 sec.	17 min. 27 sec.
Trial Two	23, 280	18, 727	24, 000	97/ 79	86 min. 32 sec.	33 min. 35 sec.

The 'Egress Time After End of Game' 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 (a common trend). The criteria used to identify the onset of the Total Egress Time was the point in time in which 100 spectators had left the stadium over a period of three minutes. Approximately 17% of the spectators had left during the game and only their exit usage was counted. That egress data from prior to the end of the game is informative for assessing the variability in egress density prior to the conclusion of the game where it may be followed by a sudden more pronounced egress as seen in trial 2. The measure to start recording is arbitrary but applied to both experimental trials. Note that continuous filming of the stadium for the full event was not possible as this is typically restricted by the broadcaster who would have full filming permission of the grounds for recording the game itself.

4.1 Movement Characteristics and Demographics

Using data from the final preliminary trial, four new movement speed profiles were created for the following demographics: children, young adult, adult, and senior. These movement speed profiles consist of statistical distributions (mean, median, max, min, and standard deviation) of observed walking speeds for each demographic. Videos taken by the authors' cameras during the main trials were analyzed to determine the expected demographics of capacity football events in Canada. The data collected was extracted from two videos making up a total of 21 minutes and 6 seconds, filmed continuously.

In all trials, the camera resolution was sufficient to determine estimates of each individual's age category. Children were determined using their height and because they were often accompanied by an adult. When determining the elderly, the colour of their hair and facial features were used. When differentiating between young adult and adult, the authors used facial features as well as group behaviour to estimate their age category. Published images are obscured (see ethics statement).

The average walking speeds were used to create the new movement profile and were derived from the footage taken from camera position 2' in the last preliminary trial which permitted a perpendicular to the standing walkway and stairs view. The walking speed was determined by viewing a concourse hallway (Figure 2), and measuring the time required for individuals to travel across between two stairs (13 m). Speeds were calculated manually and checked by multiple researchers to reduce subjectivity (they conformed with little to no difference). Data for walking speeds for each demographic while unobstructed was created (Table 2). They are generally slower and have more deviation than the Fruin profile. Obstructed speeds were also monitored.

Filming of egress in the main trials was analyzed. The age distribution averaged for the main trials was found to be 6% children, 29% young adults, 53% adults, and 12% elderly spectators.

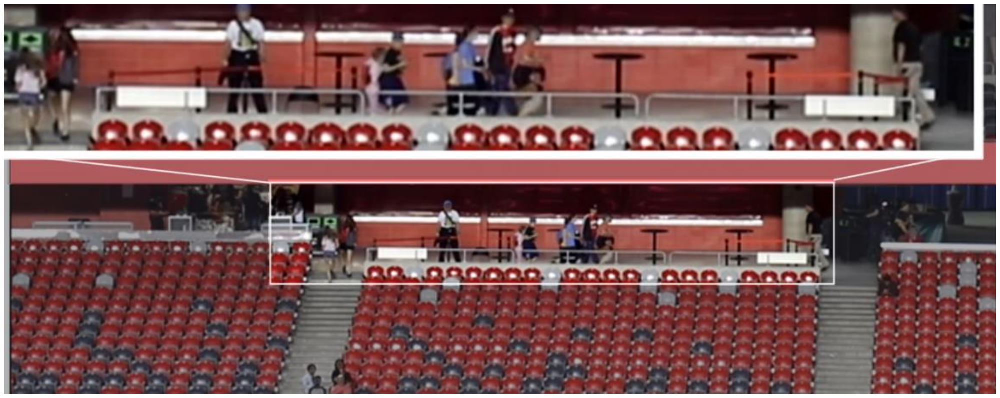

Figure 2a. Concourse used for walking movement profile (Unobstructed)

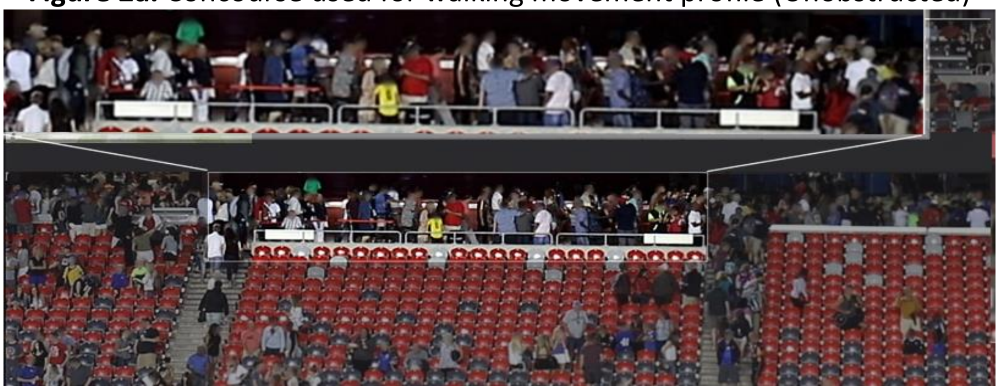

Figure 2b. Concourse used for movement profile (Obstructed)

Table 2. Data of Unobstructed Movement Profiles on a Flat Plane

Demographic	Population	Walking Speeds (m/s)				
		Max	Min	Mean	Median	Std Dev
Adult	354	1.86	0.59	1.05	1.00	0.23
Elderly	60	1.30	0.41	0.92	0.91	0.30
Young Adult	42	2.25	0.81	1.32	1.18	0.51
Child	55	1.63	0.62	1.15	1.18	0.23
Fruin	-	2.05	0.65	1.35	-	0.25
TOTAL	511					

4.2 Way Finding (Time of Egress and Exit Use)

Graphs of the observed egress during the trials were created (Figures 3 and 4) and show that the egress time in Trial Two was extended by 91% compared to that of the first trial. This was due to the closure of the East Bridge in Trial Two, which required people to walk further and in more congested conditions to reach their exit, and the close game score which encouraged people through commitment behaviour to stay in their seats until the end of the game. 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 is significantly increased.

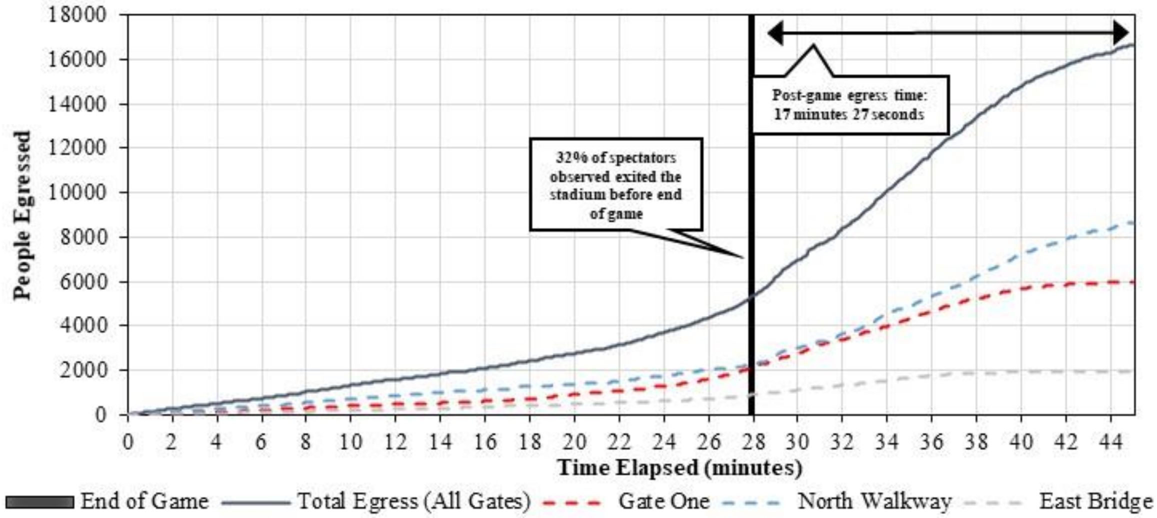

Figure 3. Trial One Egress Over Time

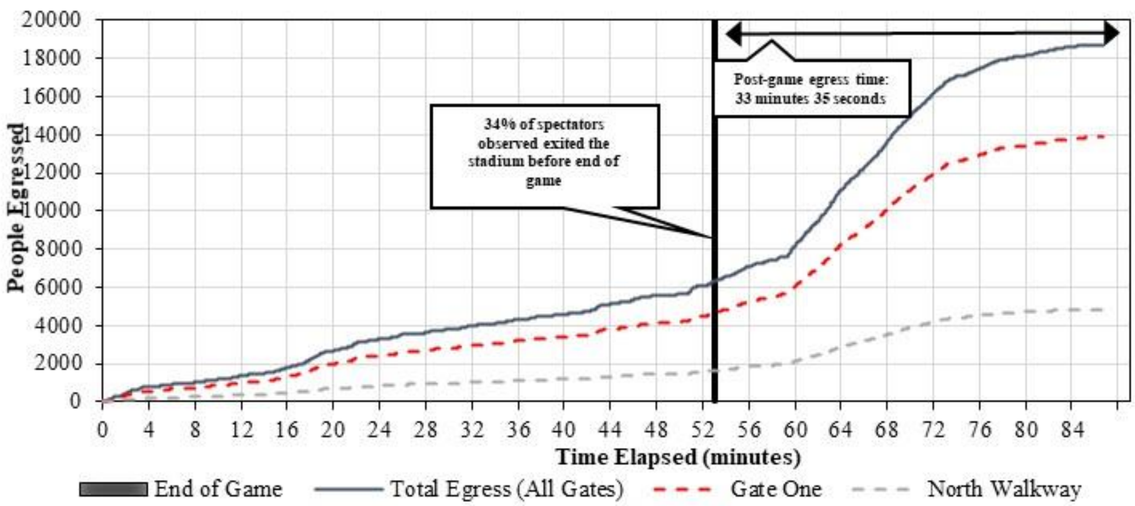

Figure 4. Trial Two Egress Over Time

Next, the gate utilization for ingress and egress for each event was reviewed and summarized. 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 influence of familiarity 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 and Kimura 1988). 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. Spectators migrated towards the wider exit, Gate One, which provided approximately quadruple the exit-width capacity and therefore reduced potential for bottlenecking.

Since this behaviour was presented, the recordings of both trials were further analyzed to see how many people from each stand were leaving using each exit. These counts appear in Table 3. Each individual was tracked from seat location to exit choice manually by the authors. This allowed the authors to better understand how spectators way find and choose their egress route. This table shows that individuals will not choose the lowest cost path (the path that allows them to reach an exit in the shortest possible time) and that their exit choice is unaffected by where they are sitting. As a result, a two-directional flow or a cross flow effect was observed in both trials. The cross flow is caused by individuals from the North Stands exiting using Gate One, while individuals from the South Stands exit through the North Walkway. The effect was more prominent in Trial Two because of the East Bridge closure. This is seen in Table 3 since Trial Two shows more people from the North Stands using the Gate One exit and more people from the South Stands using the North Walkway in comparison to Trial One.

Table 3. Exit choice in comparison to seating for Trials One and Two (during egress near and after the end game)

Trial	Stand Location	North Walkway	Gate One	East Bridge
Trial One	North Stands	7479	1461	0
	South Stands	1187	4517	1975
Trial Two	North Stands	3221	6885	0
	South Stands	1634	6987	0

4.3 Crowd Behaviour (Density and Congestion)

Flow (pedestrians per minute) over time, as well as flow rate through the exit (pedestrian per meter per minute) over time were also created for each trial (Figures 5 and 6).

As seen in Figure 5a, the East Bridge has the highest flow throughout most of the egress, while Gate One has the lowest. Gate One is the widest exit. Therefore, while more individuals are using Gate One, there is a higher flow rate at the other two exits (see Figure 5b). Furthermore, the East Bridge has a pinch point, an area where flow is restricted by a narrowing of the path. This causes a much higher flow rate to occur throughout the egress. This statement is also true for Trial Two, in which the flow over time for the North Walkway is higher than Gate One despite more people exiting through Gate One (see Figure 6a). In addition, Figure 6b shows the flow rate of the North Walkway is much higher than the Gate One exit throughout the egress explained by the difference in width of the exits.

When comparing the two trials, it is evident that the North Walkway has a higher flow rate than Gate One, which is caused by the difference in exit width. However, the flow and flow rates vary between trials due to the closure of the East Bridge exit. Figures 5a and 5b show that the East

Bridge has the highest flow and the highest flow rate for a large portion of the egress. In Trial Two, the closed East Bridge exit resulted in a higher flow over time for the remaining exits. However, the North Walkway flow rate decreased while the Gate One flow rate increased. This is because a much higher proportion of the population egressed through Gate One in Trial Two compared to Trial One. The overall egress in Trial Two being slower than Trial One is partly caused by the proximity of the exits though this did result in a substantial reduction of peak density at the gates between the two trials. Despite this, with the East Bridge closed, the spectators were forced to exit out of the same approximate area in the stadium. Because of this, the crossflow effect observed from the first trial was amplified causing queuing to occur and higher flow rates to form prior to the actual exits in that space. A delay of 6-7 minutes between the end of match and a spike in flow was observed in Trial 2. This is attributed to the premovement and movement for people to make their way through the stands to the exit, as flow and egress counts were measured at the exit. The close score of Trial 2 contributed to this as it encouraged people to stay in their seats right until the end of the match, compared to Trial 1 where more people were already in the process of leaving before the final buzzer.

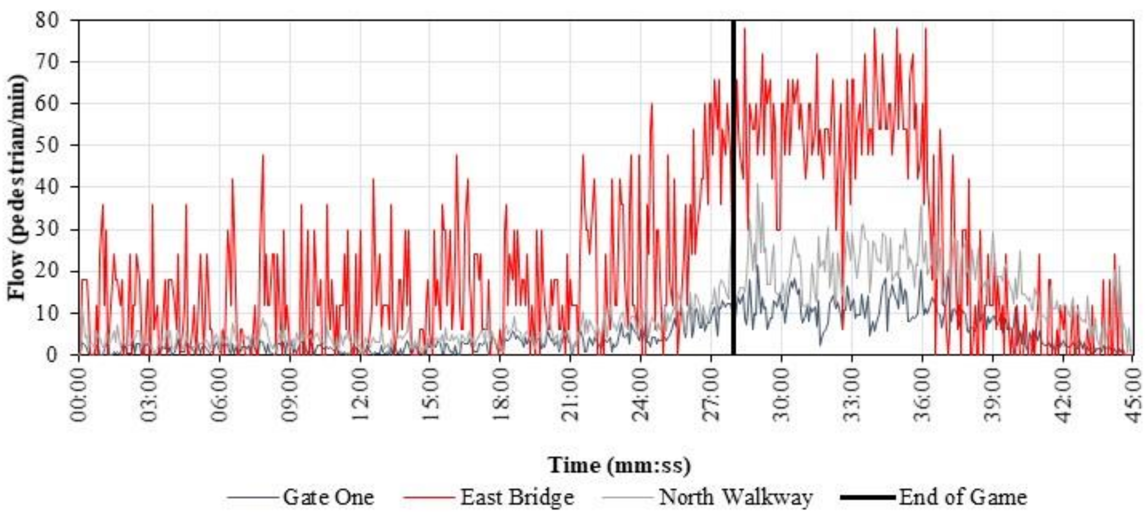

Figure 5a. Trial One Flow Over Time

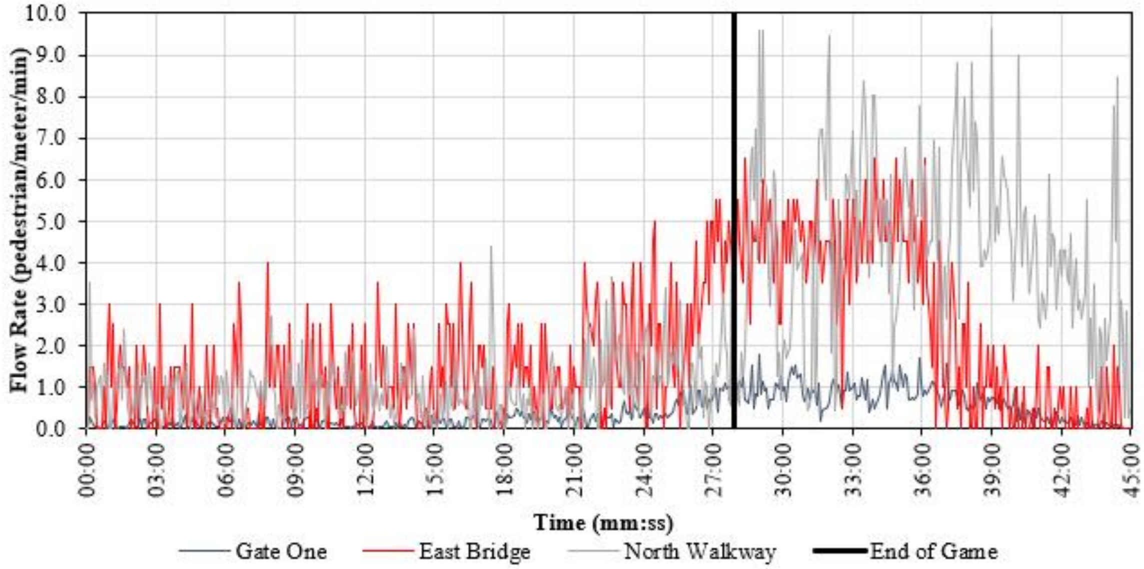

Figure 5b. Trial One Flow Rate Over Time

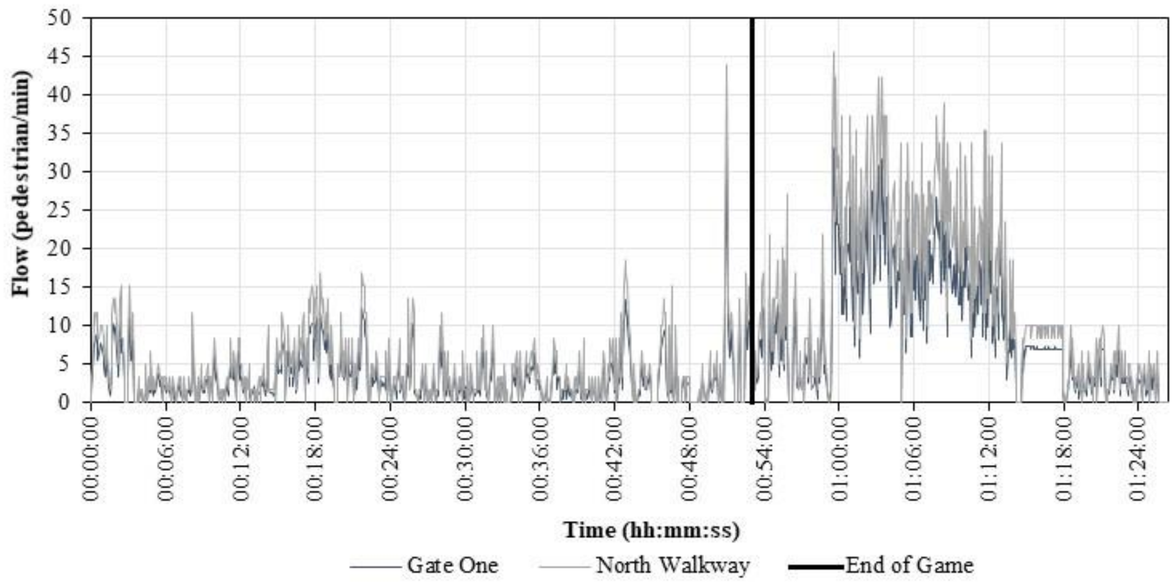

Figure 6a. Trial Two Flow Over Time

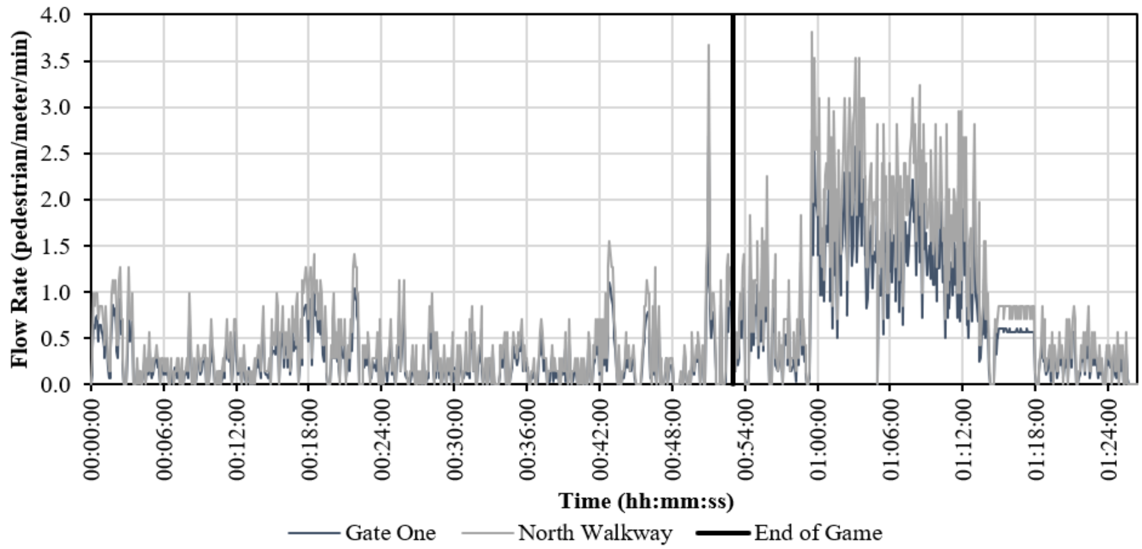

Figure 6b. Trial One Flow Rate Over Time

Despite the increase in flow rate seen in Figures 5b (at 26 minutes) and 6b (at 59 minutes), the flow rate is less than what would have been had everyone egressed at once. Approximately one third of spectators that used the filmed exit gates had left before the game's end in both trials. In Trial One, the researchers attributed this behaviour to the inclement weather, with many spectators appearing to leave the premises prior to the game ending to escape the adverse weather. 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. This occurred during Trial Two, however the close game score resulted in a large crowd gathering 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 (see Figure 7). The build up of the crowd results in higher densities which slows the movement of other individuals who are trying to exit. When the game ended, a gate rush occurs in which the crowd simultaneously disperses and exits (see Figure 7). This crowd led to an immediate and significant increase in flowrate through the exits upon the final game buzzer. The early egress of pedestrians naturally means that there are fewer people in the stands at the end of the game than during the event. Additional factors affecting this early egress may lead to different periods of high flow depending on the number of people remaining in the stands at the final buzzer. While outside of the scope of this paper, this has most significance for mid-game emergencies or evacuations, where a higher number of people still in the stands may be of greater concern.

Figure 7. (left) Crowd build up prior to the end of the game, (right) Crowd dispersion (gate rush) at the end of the game

The relationship between speed and local density from the last preliminary trial data collected can be seen in Figure 8, which shows the inverse relationship between speed and density with three experienced levels of service differentiated (based on pedestrians per square meter from Fruin's Level of Service). The local density in Figure 8 is determined from the space of the linear corridor width and length (see Figure 2). The length is taken as the distance behind the stand considered (13m), and the width being that of the travel path (7.6m). The number of people on average in the travel path during an individual transit of the length was used for the density calculation. The resolution of the camera permitted an accurate count of population in the linear path. Figure 8 also exemplifies the variable nature of the walking speeds with trend to slower speeds with increased density. Elderly persons tend to have slower movement with higher correlated density. In general, the scatter is high, but an overall reduction in walking speeds can be seen for each of the regions as Level of Service decreases from A to C. From the data collected, it is evident that the density of the crowd controls the speed at which the crowd can egress.

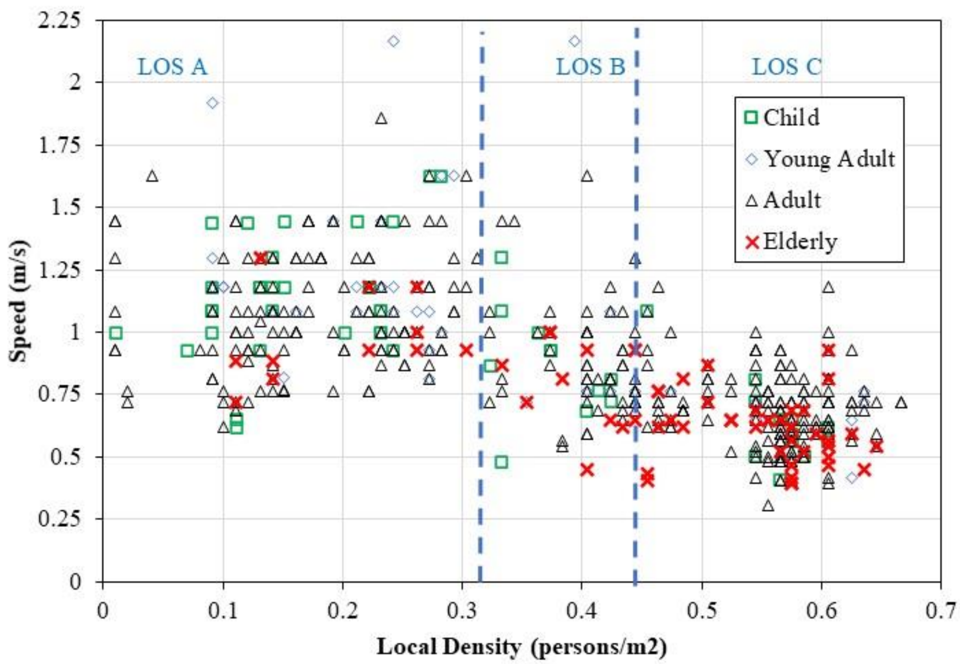

Figure 8. Speed Versus Local Density (n=736)

5. Conclusions and Future Research

The recordings herein were observed and analyzed for specific behaviour such as their movement speeds, route and exit choice, as well as areas of high density and congestion. The demographic distribution was determined. Furthermore, the trials showed that the majority of spectators use the same exit to egress as they did to ingress. Data regarding exit choice based on their seating were also compiled from the trials to be implemented in the model. It was found that a two directional cross flow effect was created by individuals egressing without using the lowest cost mindset. This caused congestion at the intersection between gate exits. The results have significance towards future efforts to building a fully predictive route choice model in the future.

A new movement profile (based on spot speeds) was derived from the final preliminary trial which divided the population into four demographics: children, young adults, adults and elderly. The movement profile consisted of walking and stair speeds for each demographic while obstructed and unobstructed. With the exception of young adults walking while unobstructed, the Fruin movement profile was faster than the new movement profile by as much as 31%. Future research should consider examination of speeds over a longer distance to assess influences of speed change related to stimuli and to fatigue. In our observations, spot distances were only recorded in close proximity to seating.

A limitation to this study is that the data and findings here are specific to Canadian football stadia. While this study found speed did have an impact, a question might be if it is actually the architecture of the stadium (i.e., stadium size, gate size and pinch points) that was the controlling factor. International stadia vary in these architectural features and even design criteria. In addition, various events may be held at different stadia internationally which results in different cultures, demographics and therefore movement. To fully explore these effects, studies need to be completed in various stadia locations and events with different crowd compositions.

Ethics Procedure

Ethics clearance for data collection was granted by the university on the basis of an internal university TD1/ TD2 process (Thesis and Dissertation Proposal by student researchers and Human Participants Research Protocol) that specified: filming permission from the stadium was granted, that standard information notices to attendees indicating that they will be filmed was performed, that ticketing indicated filming in progress, and that individuals were not readily identifiable in films or photos that would be published (hence image quality is downgraded for publication herein and altered to obscure facial reference), and filming archives were to be stored externally.

Data Availability

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Statement of Authorship

All persons who have meet authorship criteria in this manuscript are listed as authors. These authors certify that they have participated sufficiently in the work to take public responsibility for this manuscript's content, including the participation in the concept, design, analysis, writing, and revision of this manuscript. Those that do not meet these criteria are listed in the acknowledgements.

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