How can crowd behaviour modelling be used to prevent and respond to violence and antisocial behaviour at Qatar 2022?

Case study

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This case study has been produced as part of an independent research project conducted for Qatar University by RAND Europe on ‘Connections between misuse of alcohol, antisocial, violent and destructive behaviour at major sporting events, and promising strategies to minimise the incidence of and harm from these behaviours’.

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Key findings

- Crowd behaviour modelling (CBM) is the practice of simulating and predicting pedestrian movements within a space such as a stadium, using specialist modelling software.
- It informs the physical design of stadiums as well as the management of people and crowds within a space once stadiums are built and in use, to minimise the risk of and harm from any violent or antisocial behaviour.
- CBM can capture the complex cultural, individual and environmental differences in how people move in a space to predict how mixed crowds behave.
- CBM is most effective when it is collaborative and iterative between the experts carrying out the modelling, the client and relevant parties such as stadium security officers.
- CBM allows event planners to see how features of the environment, such as using wayfaring strategies or reducing queuing time for security, have an impact on crowd behaviour and safety.
- This case study investigates if and how those planning Qatar 2022 could make use of CBM to enhance the safety and security of the event. Drawing on the experience of crowd modelling experts, it offers practical tips and lessons about how to put CBM into practice.
1. Introduction

This case study is part of a research project which RAND Europe was commissioned to undertake by Qatar University, examining violent and antisocial behaviours at football events, the factors associated with these behaviours, and strategies to prevent and reduce their occurrence. In line with the overall aim of this study, this case study offers early reflections on these topics in relation to the 2018 FIFA World Cup, held in Russia.

The aim of this case study is to explore the potential for crowd behaviour modelling (CBM) to inform crowd management strategies to minimise the risk of violent or antisocial behaviour taking place during the 2022 FIFA World Cup in Qatar, and to reduce harm if it does take place.

The case study builds on evidence identified in earlier stages of the project relating to violent and antisocial behaviours at football events and factors associated with these behaviours, as well as interventions to prevent and reduce violent and antisocial behaviour at football events (Strang et al. 2018; Taylor et al. 2018).

It is based on a review of academic and grey literature, desk research on relevant tools and applications, prior experience in CBM among the RAND Europe research team, and interviews with internationally renowned experts who have experience of applying CBM.
2. What is crowd behaviour modelling?

Crowd behaviour modelling (CBM)\(^1\) is the practice of simulating the flow of pedestrians in a virtual environment. Specialist software is used that allows each individual (called an ‘agent’) or group to be programmed to navigate from their origin to their destination within the modelled area. An example would be to model a football fan arriving at the stadium parking lot, navigating the crowds towards their entrance gate, wandering the concourse area to find a food vendor, and finally arriving at their seat inside the stadium. CBM predicts the interactions of (often) thousands of pedestrians, each with their own individual origins, destinations and attributes, and from this builds models of how large crowds will move and behave. As an example, Figure 2.1 shows pedestrian modelling at the 2016 Olympic Games in Rio de Janeiro, with each individual's movements simulated within the Maracanã stadium complex (AECOM 2018). The areas shown in red indicate areas of heavy pedestrian traffic that may need to be optimized, redesigned or more heavily policed.

Figure 2.2 shows an example of how the actual paths taken by individuals at a train station can be captured by video.\(^2\) This real-life data can be used both as an input to CBMs as well as a way to evaluate their accuracy at representing real-life conditions. In this image, the green dots indicate starting points, and the red dots ending points (Pedestrian Dynamics 2013).

Figure 2.3 shows the output of CBM at Yankee Stadium in New York City, with individual spectators flowing through the stadium as they would in real life. To build this model, experts started with 2D architectural drawings, then created a 3D model of the stadium including stairways, ramps, elevators, etc. Information about the paths and rules for each spectator’s movement (such as where they would enter and where their seats were) was based on data from ticket sales. Different scenarios were tested including regular operations, evacuations, access by medical staff, and blocked exits. Modelling analysis was used to inform stadium management on how best to locate stadium staff and security to minimise queues, relieve crowded areas and improve stadium security.\(^3\) The different colours of spectators represent different user classes. Attributes can be assigned to each individual such as walking speed and directness, as well as gender, age or which sports team they are supporting. These attributes can be set to influence each agent’s behaviour.

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2. For a video demonstration, see Pedestrian Dynamics (2013), for a brief overview of stadium crowd simulation see Davidich et al. (2013).

3. This uses the STEPS CBM software; Mott MacDonald (2018).
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The primary purpose and value of CBM is in informing real-world design and operations. This can be done to reduce the risk of dangerous congestion levels, violence and antisocial behaviour. Unlike a traditional transport or economic model, CBM is less concerned with precisely fitting to observed data. The focus instead is to use approximate simulations to inform and influence the real-world situation.

Agent-based CBM is limited to analysing the physical movement of people within a space. It cannot be used as a predictive tool for the occurrence of certain behaviour such as violence or antisocial behaviour. The main value of CBM is therefore in trialling different designs, operations and layouts to see how the crowd will respond to different scenarios such as a panic situation, different demographic makeup of the crowd and peak congestion levels.
3. Using crowd behaviour modelling to reduce and prevent violence and antisocial behaviour at international sporting events

CBM is used to inform the design and operations of a given space to reduce crowding and (among other things) reduce the risk of negative crowd interactions. The outputs of CBM can be used to adjust physical space and environment, for example by widening a passageway, restricting the length of a queue, or adding another ticket dispenser. The simulation becomes a virtual playground that allows users not only to test, but also to visualise problematic areas of pedestrian congestion. Evacuation and other emergency scenarios can be simulated, with all agents in the simulation attempting to exit the area of interest as quickly as possible.

By experimenting with different scenarios, informed decisions can be made on how to improve comfort and experience, save costs, improve functionality, design operations, and ensure the safety of a congested space (Leeson 2015).

Research undertaken for this case study did not find explicit examples of CBM being employed primarily to prevent violence and antisocial behaviour; experts felt instead that the models would be particularly useful for planning how crowds might react to an incident of violence. However, understanding how people will move in space is a vital input to inform policing and crowd management techniques, which in turn might prevent violence and antisocial behaviour. Findings from other parts of this research for Qatar University (Strang et al. 2018) have highlighted that separating rival fans, and using screens and ‘human corridors’ of police officers to guide where spectators move, can be effective management strategies. The research has also found that spatial factors affect crowd behaviour. These findings indicate the potential for CBM to form a useful input to management planning.
4. How much space to allow for increased safety?

In the CBM realm there are industry standard targets for the amount of space pedestrians should have, referred to as ‘Levels of Service’ (LOS). Level A is the least crowded and Level F is the most crowded. The figures below show that as crowding increases, the flow and speed of the crowd reduces. Sustained periods of LOS F conditions will quickly deteriorate and bring pedestrian flow to a halt. These ‘crush capacity’ conditions may not only be inefficient and uncomfortable but also can often be very dangerous due to stampeding, trampling and crushing. The density and flow of crowds greatly influences the reaction to events within the crowd, such as any incidence of violence or antisocial behaviour. Higher-density crowds and spatial bottlenecks will exacerbate such dangers.

The LOS standards are used to minimise the occurrence of LOS F to ensure that crush capacity is avoided (Wong 2007). However it is expensive, inefficient and impractical to provide LOS A in naturally crowded environments such as public transport terminals and sports venues. These spaces inherently require large volumes of people to fit into space-restricted environments such as a train platform or the surroundings of playing fields. LOS standards between B and E are therefore more realistic targets, depending on the circumstance and limitations.

**Figure 4.1. Fruin’s LOS metrics**

<table>
<thead>
<tr>
<th>Level</th>
<th>Density (ped/m²)</th>
<th>Space (m²/ped)</th>
<th>Flow Rate (ped/min/m)</th>
<th>Flow Rate (ped/min/ft)</th>
<th>Av. Speed (m/s)</th>
<th>Av. Speed (f/min)</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A</td>
<td>&lt; 0.27</td>
<td>&gt; 3.24</td>
<td>&gt; 38</td>
<td>&gt; 23</td>
<td>&lt; 7</td>
<td>&gt; 1.4</td>
<td>260</td>
</tr>
<tr>
<td>LOS B</td>
<td>0.27 to 0.31</td>
<td>2.32 to 2.94</td>
<td>20 to 25</td>
<td>13 to 18</td>
<td>1.2</td>
<td>480</td>
<td>0.3 to 0.6</td>
</tr>
<tr>
<td>LOS C</td>
<td>0.32 to 0.43</td>
<td>1.39 to 2.32</td>
<td>15 to 25</td>
<td>10 to 15</td>
<td>1.2</td>
<td>240</td>
<td>0.4 to 0.6</td>
</tr>
<tr>
<td>LOS D</td>
<td>0.68 to 0.72</td>
<td>0.93 to 1.39</td>
<td>10 to 15</td>
<td>9 to 15</td>
<td>1.1</td>
<td>225</td>
<td>0.6 to 0.8</td>
</tr>
<tr>
<td>LOS E</td>
<td>2.17 to 1.08</td>
<td>0.46 to 0.93</td>
<td>5 to 10</td>
<td>5 to 10</td>
<td>1.1</td>
<td>150</td>
<td>0.8 to 1.0</td>
</tr>
<tr>
<td>LOS F</td>
<td>&gt; 2.17</td>
<td>≤ 0.40</td>
<td>&lt; 5</td>
<td>variable</td>
<td>variable</td>
<td>≤ 0.76</td>
<td>≤ 150</td>
</tr>
</tbody>
</table>

Source: Still (2018a)

**Figure 4.2. Pedestrian flow vs pedestrian space LOS**

Source: Still (2018a)

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4 Examples include the 1989 Hillsborough disaster (96 people killed, 400 injured) and the 1994 Jamarah Bridge disaster (266 people killed, 98 injured). For more examples, see Still (2018b).
Figure 4.3. Fruin's LOS in STEPS crowd behaviour modelling software

Note: Red areas indicate zones of potential conflict with a large volume of foot traffic. Source: Wong (2007)
5. Inputs to crowd modelling: what factors are relevant to international sporting events?

This section summarises some of the factors that affect how crowds move and interact. The research team and expert interviewees felt that the following points are particularly relevant to the planning of the 2022 World Cup in Qatar:

**There are differences in how pedestrians behave depending on their cultural norms** (Still 2018c; The Economist 2011). Based on analysis of data on actual crowd movements, it has been found that different cultures exhibit different crowd behaviours. For instance, two French pedestrians approaching each other will most likely pass each other to their respective right-hand side. Conversely in most Asian countries the tendency would be to pass each other on the left. There does not seem to be a correlation with which side of the road is driven on, since English pedestrians will also tend to pass each other on the right despite driving on the left.

**At an international sporting event, the dominant cultural norms may change from match to match depending on the nationalities playing.** CBM software can account for such differences, and the output of the models can inform operational decisions. For instance, during a match between England and France pedestrians should be ushered to the right-hand side of a corridor, while during a match between China and South Korea, they should be ushered to the left-hand side.

**In addition to cultural norms, a range of personal characteristics influence how someone moves on foot and diversity amongst individuals will greatly affect the behaviour of the crowd** (Bekris 2018; Egan 2018). Age, disability, home country, alcohol intoxication, whether you are a tourist or a local, whether you are alone or in a group, your affiliation with a particular team and level of enthusiasm have all been shown to affect individual-level behaviour in crowd situations (Egan 2018). A mix of attributes for the individuals in a particular crowd can be simulated in CBM software, resulting in model outputs where different agents move at different speeds and with varying levels of directness to their eventual destination. Given an estimate of the distribution of these individual traits, crowd models can then predict the resulting interactions from this mix.

**Certain locations in stadiums will naturally attract people.** People congregate near areas such as toilets, ticket vendors, benches and information boards, and this is where a higher-density crowd might be expected (Bekris 2018). CBM allows such areas to be identified and planned for. Additionally, CBM takes into account that **pedestrians have been shown to demonstrate a natural avoidance of other people** (Moussaid et al. 2010). This phenomenon is called ‘social force’ among crowd modellers. Individuals tend to avoid crowds of people by passing around these areas of congestion. Again, CBM can take this into account.
6. Using outputs from crowd modelling

CBM can be used to evaluate numerous known tactics for improving safety and pedestrian flow through bottlenecks. Wayfinding strategies can involve using guiding lines on floors and placing obstacles on either side of an exit to avoid stampeding (Jiang et al. 2014). For stadiums, having people \textit{arrive at a more consistent rate} rather than surging just before kick-off time is an important element of holding a safe event. Sending guidelines to attendees to arrive early, and dedicating stewards to assist large groups arriving at once (such as tour buses) rather than mixing them in with smaller groups arriving at a more constant rate are commonly used strategies. Giveaways to the first certain number of people arriving are another tactic to entice patrons to arrive early (Bekris 2018; Nelson 2018). Another customisation may be to allow for longer security screening times for spectators expected to wear more layers and/or looser clothing.

For sporting events, it is important to consider the number of fans without tickets to the actual match who will congregate in public areas. This was a key finding from an evidence review produced as part of this research study (Strang et al. 2018). CBM can be used to simulate the accumulation of fans around stadiums or in ‘fan zones’ and trial different arrangements to minimise the interaction between rival fan groups and law enforcement.
7. Expert tips for effective crowd modelling

Expert interviewees identified the following tips that, in their experience, make it more likely that CBM will be accurate and useful:

**Collaborate closely with stadium security.** Stadium security managers and their staff are closest to the practical operations on the ground and can provide invaluable ‘reality checks’ to the modelling work. It is therefore imperative to collaborate early and often with security when considering CBM (Egan 2018). Building security into the design of the stadium rather than retrofittin an existing space is strongly encouraged as modelling can reveal issues such as dangerous surrounding roadways and insufficient ventilation (Egan 2018; Nelson 2018).

**Long-term security planning regarding stadium design and ‘game-day’ security operations have different needs.** Long-term security planning is more concerned with the physical design of the stadium while game-day security is more concerned with the operations within the space. Modelling can help inform security needs such as the levels of police needed, how strict security screening should be, and the need for explosives-detecting dogs (Egan 2018).

**Crowd reactions to security risks and evacuation simulations should be run to predict a stadium’s readiness in such scenarios** (Bekris 2018; Nelson 2018). Testing operations and security arrangements in practice with other games and events at the same venue is also imperative to uncovering design flaws in the space or in its operations (Bekris 2018; Egan 2018; Nelson 2018).

**CBM needs to be tailored to specific needs and thus it is important to define specific targets,** for example LOS, maximum queue length, individual security processing time, and/or evacuation speed (Egan 2018).

**Cultural norms, crowd diversity, environmental factors, geography and operations arrangements all need to be considered on a case-by-case basis for any crowd modelling work.** There are cultural norms related to the tendency to pass on the left or right, walking speeds and how closely people queue behind one another (Nelson 2018). Diversity of the crowd (e.g. age, disabilities), their queuing behaviour, interactions with different groups, arrival in large groups, weather impacts (such as intense heat or rain) and clothing (and thus security screening implications) are other specific differences to consider and build into CBM (Bekris 2018).

**The geography of the surrounding area is important to take into account,** including proximity to adjacent buildings and the configuration of stadium gates and access from roadways (Egan 2018).

**Operational factors should be considered,** such as the level of training that security and stadium staff have, crowd interaction with vendors, and internal staff with access to restricted areas (such as service people, vendors and security staff) (Egan 2018; Nelson 2018).

**Know the data and technical needs.** Interviewed experts highlighted the importance of identifying data availability and data gaps at the outset of any modelling project.

**Learn from the experience of others.** Stadiums are one of the main application areas of crowd modelling and thus there is plenty of existing expertise in the field. Stadiums in similar environments should be examined for guidance and lessons learned. The difference in urban environment and predominant modes of transport to the venue will have a large impact on how the crowd arrives and how people interact with each other and the spaces.
surrounding the stadium. For example, the Khalifa International Stadium (and the wider Doha Sports City) should seek experience from similar multi-use sporting environments such as the Maracanã stadium in Rio. In contrast, in the case of the Al-Shamal Stadium, it would be better to learn from the experiences of a stadium in a more remote location farther away from dense urban areas and likely accessed predominately by car drivers, such as MetLife Stadium in New Jersey. Stadiums in denser urban areas with access to the Doha Metro (such as the Khalifa International Stadium and the Lusail Stadium) should seek guidance from similarly situated stadiums such as the Emirates Stadium in London. Stadiums with convenient public transport access can expect less car traffic, reduced need for parking, more irregular arrival rates of spectators (large surges when trains arrive), more interaction amongst rival groups, and less clear separation between the stadium and the surrounding area (Egan 2018).
8. Practicalities: timeline, cost and software

Stadium modelling projects can be expected to take roughly one year, which includes extensive consultation between the modellers and the client to build the right requirements and iteratively assess needs.

While cost varies, crowd modelling for large stadiums typically costs hundreds of thousands of US dollars if a specialist company is hired (Egan 2018). Considering that the costs of the World Cup stadiums for Qatar 2022 is reported to be between $8bn and $10bn (Al Heialy 2016), the cost for CBM represents a very small fraction of the overall cost of the projects. CBM is also likely to offer long-term cost savings on operations by informing a more efficient stadium design.

Talking to others in similar environments is encouraged. For example, a stadium in a rural location with lots of parking will have different experiences and needs compared to a stadium in a city centre (Egan 2018).

Data and inputs needed for CBM include:

- A digital model of the physical space (such as a computer-aided design (CAD) drawing).
- Information about the number of people (how many total people arrive in the system), the mode of transport by which they arrive, pedestrian paths (where people come from and where they are headed), and service rates (such as how quickly ticket booths or security queues can process people).
- Walking speeds, crowd demographics and other context-specific factors.

If event organisers do not have this information there are a number of options: expert crowd modelling companies can provide estimates based on their experience (e.g. estimates of the time needed for security screening). Paths and volumes can be obtained through manual headcounts or software packages that can discern this from video footage (Egan 2018; Bekris 2018).

Given these inputs, specialist software packages can run simulations based on variations to any of the inputs such as expanding a waiting area, increasing the volume of passengers, or closing off an entrance gate. A wide variety of commercial software capable of CBM is available.5

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5 Examples of crowd modelling software include (in no particular order): PTV Viswalk, Oasys MassMotion, Pedestrian Dynamics, Crowd Dynamics, Simwalk, Paramics (Urban Analytics Framework), Legion, STEPS, INCONTROL, SMART Move and Golaem.
9. Conclusions and key lessons for Qatar

Findings from other parts of this research project have highlighted that spatial factors are important in determining crowd behaviour, and that crowd management strategies can be effective in reducing violence and antisocial behaviour. Strategies include separating home and away fans and using screens and police officers to guide groups as they arrive at and move into the stadium.

Based on interviews with international experts in crowd modelling and desk research of available literature, this case study looked at the possibility of using CBM to support crowd management during the 2022 World Cup (and other international sporting events hosted in Qatar).

The World Cup brings together individuals from a range of national and cultural traditions, with different norms about behaviours and movement in a crowd, which means that crowd behaviour – and appropriate management strategies – might change depending on the makeup of the crowd at a given match. CBM can be used to help plan bespoke crowd management approaches for Qatar 2022. A finding from other parts of this study indicated that it is common at World Cup matches for fans without match tickets to congregate in public areas. In addition to using CBM within the stadiums, Qatar 2022 planners could use the method to undertake modelling in other areas where it is expected fans will congregate, such as fan zones and public transport stations.

Stadium modelling projects can be expected to take roughly one year. While cost varies, crowd modelling for large stadiums typically costs hundreds of thousands of US dollars. The data and inputs needed by CBM software models include a digital model of the physical space of a stadium or other area and information about the number of people, how and when they arrive, pedestrian paths, and the service rates of the facilities. It is also useful to know walking speeds, crowd demographics and other context-specific factors.

Experts offered tips to anyone wishing to undertake CBM, which 2022 planners may wish to take into account:

- The development of models should be undertaken with close collaboration between contractors undertaking the modelling and the individuals who are responsible for the day-to-day operational management of the modelled space.
- CBM adds most value when it takes place early enough for the layout of key outdoor spaces and stadiums to be changed according to the results of the modelling.
- CBM is most effective when highly tailored to the specific details of the space and the make-up of the crowd.
- CBM should be undertaken in parallel with operational planning such as the training given to all those involved in managing the space (police, volunteers, security personnel, etc.).
- Stadiums in similar environments should be examined for guidance and lessons learned.
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About this case study and the research project for Qatar University

Qatar has hosted a number of international sporting events and will host the World Athletics Championship in 2019 and the 2022 FIFA World Cup. In preparing for these events, there is an opportunity to learn from research into the prevalence, nature and causes of violence and disorder at other sporting events that have drawn together spectators from a range of countries with diverse cultural and religious characteristics, and to draw on promising practices to prevent and respond to these harms.

Qatar University commissioned RAND Europe to research the current available evidence on these topics to identify insights that may be relevant for Qatar’s preparations.

Project aims

The goals of this project were to understand:

1. What has been the nature (types of behaviour, types of perpetrators, victims, location, etc.) and prevalence of antisocial, violent and destructive behaviours among populations watching and attending major sporting events, in particular international football matches?

2. What factors are associated with these behaviours (e.g. alcohol misuse, ethnicity and nationalism; group dynamics) and what is the nature of the association?

3. What approaches have been taken to prevent and respond to these behaviours?

4. To what extent have these approaches proved effective?

5. What specific recommendations follow from the findings that could be used in Qatar in planning for the World Cup in 2022, and where are the opportunities for further research?

Project methods and approach

The project drew mainly on the identification and critical assessment of international literature and media reports, as well as interviews with a wide range of stakeholders in Qatar and internationally.

Full details of the methodology for the research can be found in the final evaluation report available at https://www.rand.org/randeurope/research/projects/violent-and-antisocial-behaviour-at-football-events.html

About this case study

A total of six case studies were undertaken to investigate a range of issues relating to safety and security at international sporting events.

This case study drew on two data collection methods. Firstly, a series of telephone and email interviews were undertaken with four internationally renowned experts who have experience of applying CBM. The interviews were semi-structured and took approximately 30 minutes. We developed broad interview protocols tailored to each group of key informants, which served as the basis for each interview. In addition to questions included in the protocol, this approach allowed the team to discuss unanticipated topics that interviewees considered relevant.

Secondly, a targeted review of academic and grey literature was conducted to identify sources relating to CBM, and desk-based research examined relevant tools and applications. In addition, the case study was informed by prior experience of CBM among the RAND Europe research team.
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Details of the other case studies and wider project results are available at https://www.rand.org/randeurope/research/projects/violent-and-antisocial-behaviour-at-football-events.html. These are of interest not only to those responsible for preparing for upcoming events in Qatar, but to anyone involved in the safety and management of international sports tournaments.

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