UNIVERSITY
OF ALBERTA

PROACTIVE MANAGEMENT OF THE 2026 WORLD CUP FAN MARCHES

TRANSPORTATION TECHNOLOGY TOURNAMENT

ZANIB WAJAHAT PANNU

IN COLLABORATION WITH
PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

NOCoE
National Operations Center of Excellence

MAY 31, 2025

PROACTIVE MANAGEMENT OF THE 2026 WORLD CUP FAN MARCHES

SUBMISSION DATE MAY 31, 2025

SUBMISSION BY

ZANIB WAJAHAT PANNU
BSc Civil Engineering, University of Alberta

INDUSTRY ADVISORS

DAVID L. ADAMS, P.E.
Senior Manager - Traffic Operations Division; PA Department of Transporation

KATIE MCLAUGHLIN
Volpe National Transportation System Center; U.S. Department of Transportation

ACADEMIC ADVISOR

DEBABRATA PAUL
Ph.D. Candidate & Graduate Research Assistant; Department of Civil & Environmental Engineering; Florida International Univeristy

---

ACKNOWLEDGEMENTS

I would like to sincerely thank the National Operations Center of Excellence for organizing this competition. This experience was an invaluable opportunity for me to deepen my understanding of developing Intelligent Transportation Systems for a real-world transportation challenge. I am especially grateful to Debabrata Paul, Katie McLaughlin, and David Adams for their ongoing support and guidance throughout the development of this report. In particular, Debabrata Paul assisted in the writing of 2.4 and the high-level solution overview.

TABLE OF CONTENTS

List of Figures

List of Tables

1 OVERVIEW

This proposal is submitted for the 2025 Transportation Technology Tournament in response to the issue of pedestrian safety during fan marches at the 2026 World Cup in Philadelphia, Pennsylvania. The solution presented in this document leverages a variety of Intelligent Transportation Systems (ITS) technology. ITS is a form of technology that uses a combination of information and communications technologies to improve traffic safety and transportation management [1]. Some examples include dynamic traffic signal control, vehicle-to-infrastructure communication systems, and Bluetooth detection, among others. ITS technologies can also use big data, artificial intelligence (AI) engines, and digital twins to enhance transportation and traffic safety management.

2 PROBLEM STATEMENT

2.1 PROBLEM DESCRIPTION

Philadelphia, Pennsylvania is one of the host cities for the 2026 World Cup with Lincoln Financial Field as a host site. The Lincoln Financial Field is located over 3 miles from the Centre City and is expected to welcome 60 000 visitors per match, with many more fans gathering throughout the city to take part in the many soccer related festivities. In addition to the matches, fans will travel around the city to areas like hotel zones, bars, fan fests, and restaurants. Fan marches are a major element of soccer culture, where groups of fans walk together to the matches and are expected to occur while Philadelphia hosts the World Cup. Although many marches will be organized and planned in advance, marches can also be impromptu, involving unpredictable movements or movements along undesignated routes. Marches contribute to a festive atmosphere however, this unpredictability and the large crowd volume poses challenges regarding pedestrian safety in vehicle dominated corridors. This presents a complex transportation challenge as the City of Philadelphia will need to ensure the safe and efficient everyday movement of fans around the city and during marches without major disruption to city traffic over the course of the 39 day tournament.

At large-scale events, many crowd management strategies involve crowd monitoring and incident reporting. However, risk factor monitoring and predicting can also provide significant value, as this information can lead to an early response so that risks would not transpire into incidents in the first place. Indicators of growing risk such as pedestrian-vehicle near miss interactions [2], overcrowding [3], pedestrian spillage onto roadways, and crowd surges and bottlenecks [4] provide crucial information for where pedestrian infrastructure and/or traffic control may be insufficient. Therefore, this project proposes a system that detects early risk signs in a single, dynamic system during organized and spontaneous fan marches. This system allows for proactive intervention based on predicted and real-time conditions. ITS technology such as sensor-based detection, video analytics, AI models, and geographic information systems (GIS) will be used to create this adaptive system that continuously collects and analyzes warning sign data to aid in efficient traffic management operations throughout the multi-day World Cup.

2.2 STUDY AREA

The matches will take place at Lincoln Financial field, which serves as a focal point for this project. Marches of people will head towards the stadium thus, designated march routes will be implemented, and they may be any of the streets within the green box marked in Figure 1. Designated march routes may include two key corridors: 7th Street and Broad Street starting at Vine Street Expressway (I-676). Given this context, traffic management strategies that are adaptive and targeted are crucial to maintaining safety and mobility for both fans and vehicles during the tournament. The field borders the Delaware Expressway (I-95), one of the highest volume roadways in the city [5]. As well, South 11th Street and Pattison Avenue serve as important connector roads to I-95. Thus, the presence of these roadways require special consideration to ensure fan and vehicle safety.

In addition, pedestrian movement to nearby pubs, restaurants, public gathering places, and hotel zones are relevant to this project as safety during impromptu marches is being considered. Franklin D Roosevelt Park, Marconi Plaza, and the XFinitiy Live! Philadelphia entertainment complex are nearby public places and thus are likely fan gathering places. These areas are places where unplanned marches may initiate, especially as fans move in and out of venues. A significant number of fans are expected to use public transit networks throughout the tournament, for transportation and as congregation points. Thus, the SEPTA Metro Network, and in particular the Broad Street Line with NRG Station near the stadium [6], is expected to experience increased usage, as a critical component of the City's overall mobility strategy during the World Cup [7]. Bus routes 4, 17, and 37 will also likely see increased usage as accessible and convenient ways to get to Lincoln Financial Field [8].

The City of Philadelphia has ITS and safety infrastructure implemented around the city and in the vicinity of Lincoln Financial Field. Lincoln Financial Field is equipped with video surveillance [6]. Additionally, the city has pedestrian refuge islands at many major intersections [9]. In the past, the City of Philadelphia has used LiDAR technology for planning purposes [10].

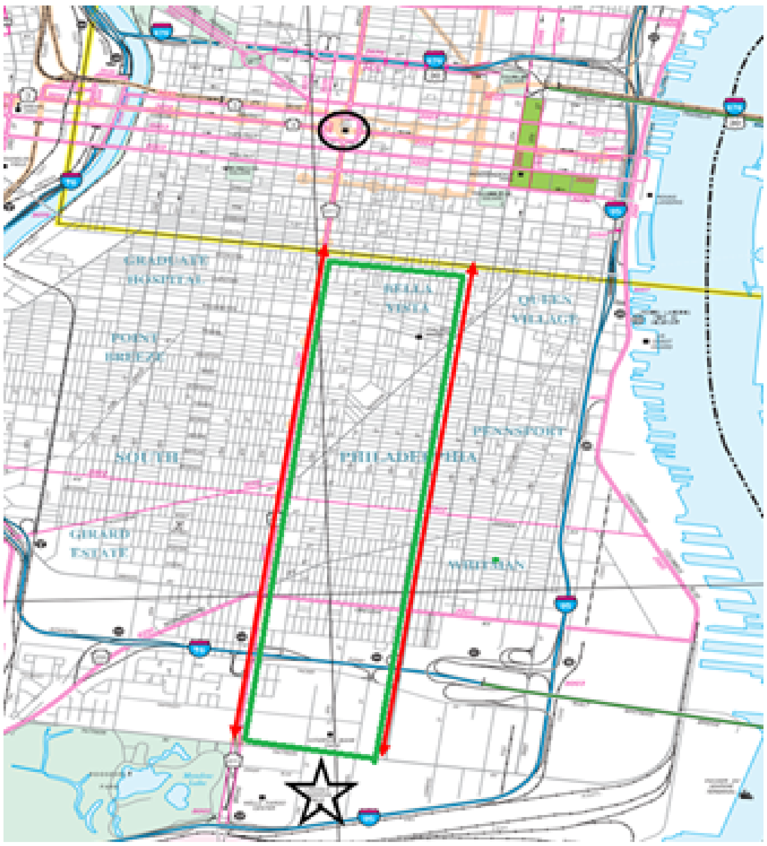


Figure 1: *Lincoln Financial Field and surrounding areas in Philadelphia, Pennsylvania. Any streets within the green box and the streets marked in red are potential designated march routes. Lincoln Financial Field is marked with a star.*

2.3 STUDY AREA CHALLENGES

The study area poses a few challenges relevant to the solution. Major roadways in the study area are crucial for both pedestrian and vehicle mobility in Philadelphia. For example, Broad Street and I-95 are major roads with high traffic volumes thus, any safety measures impacting these areas should aim to minimize causing further congestion. Given that the tournament will last 39 days, it is not feasible to shut down the city's core for the marches. Furthermore, Broad Street has some of the highest foot traffic in Philadelphia [11] and may be used by pedestrians during the World Cup, even outside of organized march closures. However, this street is a part of Philadelphia's High Impact Network, a network where 80% of the City's traffic related deaths and injuries occur [12], thus special safety consideration is a must along this street. That being said, the Broad Street Safety Improvement project is important to note as safety enhancements are expected in this area [13].

2.4 ADDITIONAL PROBLEM STATEMENT DATA

Successful crowd management depends largely on spotting potential hazards early enough to respond swiftly and effectively. Failure to anticipate risks early on can lead to slower and less cohesive reaction time from operations and emergency response teams. This can raise the chances of dangerous crowding, congestion, and accidents like trampling [14]. Research into crowd behavior reveals that at very high densities, pedestrian movement can quickly shift from smooth flow to unpredictable stop-and-go waves and even chaotic "turbulent" motion, where people are pushed involuntarily in different directions—dramatically increasing injury risks [15]. By tracking crowd pressure, which combines how dense and how fast people are moving, safety teams can get early warnings and act before situations become critical. Without such predictive tools, emergency responses are often reactive, leading to delays that worsen crowd stress and danger [14]. This shows how essential ongoing monitoring, predictive insights, trained personnel, and clear communication are for keeping crowd densities safe and improving how quickly teams can respond at big events [14], [15].

3 DESCRIPTION OF SOLUTION

The proposed solution consists of four key phases: (1) Detect, (2) Predict, (3) Track, and (4) Implement.

1. **Detect:** A multi-sensor approach, involving 3D LiDAR, CCTV footage, Bluetooth and mobile signals, RFID and AI video analytics to capture and analyze crowd and vehicle movement data in real-time.
2. **Predict:** An AI system that will use historical* and real-time data in addition to secondary contextual factors to predict high-risk zones and future conflict points. A feedback loop compares real-time conditions to forecasts, so that the system can adaptively recalibrate risk hotspots and priority zones if necessary. For the early stages of the tournament, a digital twin will be used to simulate and predict high-risk zones and conflict points.
3. **Track:** The processed data is aggregated onto a GIS dashboard that visualizes predicted risk zones, real-time pedestrian flow, staff allocation, and incidents or accidents that have occurred, enabling continuous situational awareness.
4. **Implement:** Event operations team can use insights to respond to risks through manual and automated actions. This includes using advanced signal controllers, digital message signs, and portable changeable message signs. It can also be used when forming emergency response team strategies. Furthermore, user-friendly versions of these insights will be made available to the general public integrated through Google maps or through a dedicated app. These platforms will display real-time insights as well as any manual alerts sent in the case of an emergency.

***Historical data in this context refers to data from previous marches. For example, during the third match, 'historical data' will be data from match 1 and 2.

3.1 ITS APPLICATIONS AND STRATEGY

3.1.1 Detect

The first step is to detect early warning signs of unsafe zones to proactively solve traffic safety issues. Detection of these signs will support real-time interventions and also feed into a predictive AI engine. This data, known as the primary early warning signs, will be combined with external factors, or secondary early warning signs, that can also impact pedestrian-vehicle behaviours that can in turn, impact traffic safety outcomes. The secondary warning signs provide additional environmental context that will help train the AI system for more accurate predictions. Finally, the system will also keep track of city-wide actual incidents that occur during the tournament. The proposed solution uses a combination of 3D LiDAR, CCTV footage, Bluetooth and mobile sensing, and Radio Frequency Identification (RFID). By integrating these complementary technologies, the system guarantees redundant and reliable data in real-time, essential for the dynamic conditions of the World Cup. See Appendix, Table A.1 for a summary of warning signs, their detection method, and the recommended update frequency for real-time collected data.

LiDAR sensors will be strategically installed in high-risk zones to track crowd spillage, overcrowding, and near-misses. This includes along the designated march routes, transition points between closed and active traffic zones, crowd edges and march initiation points. To monitor impromptu march behaviour and additional fan movement through Philadelphia, LiDAR sensors will also be placed in spaces expecting high foot traffic during the World Cup which includes public places near the stadium, restaurants, bars, and near hotel zones, especially those near the stadium. Compact LiDAR sensors such as the Ouster OS1 is an appropriate option. Using the Ouster BlueCity module, this sensor can classify near miss incidents [16]. Furthermore, its size enables it to be mounted on the same poles as existing CCTV cameras, critical for integration with existing infrastructure wherever possible and also to ensure LiDAR and CCTV field of view alignment. Location and quantity of sensors will be finalized based on existing CCTV locations and existing infrastructure to reduce costs. The LiDAR provides 3D data points that can indicate patterns to create a continually updated database of problem areas throughout the 39-day tournament. As the LiDAR produces point cloud data, it is ideal for use in low light, dense, and dynamic conditions [17].

Finally, this system proposes to layer the LiDAR and CCTV footage with Bluetooth and mobile sensing. Although less precise than the LiDAR, this additional sensing helps fill spatial coverage gaps. These sensors will anonymously track the presence and movement of mobile devices, allowing operators to monitor crowd formation trends, flow direction, and dwell times. This data would be especially helpful for impromptu gatherings which may occur outside the line-of-sight and designated march routes.

3.1.2 Predict

Following data collection, the next step is to analyze and predict pedestrian behaviors and potential unsafe pedestrian-vehicle interactions in real-time. This will involve an AI-based model, leveraging deep learning and reinforcement learning techniques, which will be refined using data collected over the course of the World Cup. The primary warning signs, feedback data, and secondary external factors will be used to train the AI model so that it can forecast high-risk zones before they become dangerous and adapt as conditions change throughout the course of the tournament. Hotspot predictions will be triggered twice per match cycle: once before the match to prepare for the inflow of fans from the march and once after the match. Real-time event schedules, crowd volume estimations, and event types used by the model to predict demand allow them to implement proactive, targeted interventions for reducing pedestrian-vehicle conflicts and enhancing overall event safety.

While AI engines work well with more data, it is important that the data is well-defined and organized to avoid confusion. Furthermore, as this project deals with multiple intersections and geographical zones, metadata from the sensors should be standardized. Thus, the framework found in [18] can be used to ensure all data detected from sensors will be automatically labelled with consistent units, time stamps, and location references, and categories in a standardized manner before being used by the AI engine.

The predictive model is trained on data accumulated over the course of the tournament meaning it is limited in the early stages when such data is not yet available. To address this, a baseline crowd behaviour model will be created using a digital twin. This approach is inspired by the use of the OnePlan platform during the 2024 Paris Olympic Games. However, as OnePlan is mainly used for venue planning [19], options such as AnyLogic, PTV Viswalk, and SUMO are more appropriate to simulate movements across complex urban environments in ways that capture pedestrian behavior and account for various transportation modes. The digital twin will simulate model scenarios such as fan movement towards the stadium in organized marches to show points of overcrowding, pedestrian spillage into vehicle corridors, and pedestrian-vehicle interactions. The following inputs will be used for digital twin simulation:

- Ticket sales (with demographic information of visitor vs local, securely collected and managed with consent and aggregated whenever possible to maintain anonymity)
- March routes (for organized marches) and assumed march routes (for impromptu marches)
- Data* from the 2022 World Cup such as volumes, crowd behaviour, conditions that led to incidents** (differences in geography, attendees volumes, and event schedules will be accounted for)
- Data* from past large-scale events in Philadelphia within the last 3-5 years**, such as the 2024 Philadelphia Eagles Superbowl Parade (differences in attendee demographics, attendee volumes, and event schedule will be accounted for)
- Daily event schedule
- Location and capacity of public transit
- Land use and zoning data

*Data could include crowd flow movements, crowd density, transit data, and secondary factors such as weather
**The purpose of this data is to understand crowd behaviours at World Cup events and also at events of similar scale in the context of Philadelphia. Differences in the nature of the events is acknowledged.

3.1.3 Track

To visualize the insights from the detection data system and the AI models, a dynamic GIS map will be created. This map will act as a dashboard for traffic management teams and emergency personnel. The system will continuously track:

- Pedestrian flow and speed (Bluetooth and mobile sensors)
- Crowd density increases (3D LiDAR)
- Real-time shifts in pedestrian behaviour (3D LiDAR and CCTV footage)
- Real-time risk hotspot formations (3D LiDAR, CCTV footage, Bluetooth and mobile sensors)
- Traffic related accidents or incidents (after reporting and confirmation by event staff)
- Other accidents or incidents (after reporting and confirmation by event staff)

These inputs will be aggregated on the centralized GIS operations dashboard, where risk zones are updated automatically. Thus, if any fan behaviour occurs outside of planned events, the system can register risks such as increased pedestrian volume and potential for overflow into vehicular areas. This will allow traffic managers the ability to respond immediately. The GIS map allows visualization of risk conditions developing and fading in real time, acting as a bridge between prediction and implementation. It ensures that safety strategies remain responsive and up-to-date by the time a fan movement or crowd shift actually occurs.

As the system will be relying on both predicted risk hotspots and real-time data, a central analytics platform is required to function as a dynamic decision support tool. This tool will suggest overriding the predictive allocation of resources if needed and will be triggered by the CCTV analytics module for near misses if a severe threshold is met. This is how the system will compare real-time inputs against forecasted risk levels and hotspots. If significant deviance occurs such that the current resource deployment is no longer effective, the platform triggers an override alert to inform management teams that reorganization may be needed. The override trigger has a few design considerations. First, the threshold for override should be high enough to avoid false alarms, meaning the trigger for allocation occurs if the real-time score varies significantly from the predicted risk. Furthermore, this deviance should be sustained for a defined, significant timespan. Methodologies such as the one found in [20] can be referenced for detecting anomalies in real-time. Once triggered, the analytics platform could suggest actionable recommendations, providing decision support to operators. A log of overrides and decisions should be kept for system analysis and improvement.

3.1.4 Implement

The aforementioned components of the system provide a clear understanding of where risks are forming and where insufficiencies in traffic management lie. This information leads to the implementation phases of the system, to support both traffic management and emergency personnel as well as informing pedestrians and vehicular behaviour.

The information illustrated on the GIS dashboard will act as a live decision support tool for the traffic operations team to continually optimize and improve strategies. As the system is dynamic, implementation will need to include dynamic and adaptable measures. This includes updating dynamic message signs including portable changeable message signs that are implemented remotely and dynamic signal control. The Pennsylvania Department of Transportation (PennDOT) will likely have an incident command center at the Traffic Management Center standup (TMC) and a City Emergency Operations Center standup at the Office of Emergency Management thus the dashboard will be available at both these locations. This will allow them to strategically position themselves and coordinate with the traffic management team in real-time, to plan efficient access routes, especially useful in situations when time is of the essence.

To inform fans of risk zones, a simplified, user-friendly version of the dashboard will be made available to fans and drivers, either integrated through Google maps or on a separate app. The interface would indicate danger points, recommend alternate walking routes, and indicate any street closures or detours. This strategy completes the system's feedback loop as information is coordinated between traffic management and the public.

3.2 Scalability

This system of early detection is scalable and modular, making it easy to adapt to other large-scale events in Philadelphia and in other cities around the world. The system will improve over time as the AI engine enhances itself with training and machine learning. To improve this system, the visualization phase can expand the use of the digital twin, not just at the early phases of the tournament but to later stages as well. This would be especially helpful in determining the optimum intervention strategies. Another improvement is targeting the limitation that LiDAR sensors and CCTV cameras are fixed. Employing drones would be to improve this.

4 SYSTEM ARCHITECTURE

4.1 Functional Table

Table 1: *Systems Architecture Functional Table*

Physical Object (layer)	**Functional Object**	**Functional Object Source**	**Description**
Detection	Pedestrian and Vehicle detection	3D LiDAR Sensor	Monitors near misses by tracking pedestrian-vehicle trajectories and evasive movements.
Detection	Crowd Spillage	3D LiDAR Sensor	Monitors spillage of pedestrians onto vehicle zones by tracking volume of pedestrians involved in spillage and time duration of spillage.
Detection	Crowd Volume and Bottlenecks	3D LiDAR Sensor	Monitors crowd volume for bottleneck formation, abnormal crowd surges, and overcrowding.

Detection	Pedestrian-Vehicle Behaviour Monitoring	CCTV Camera	Captures video footage synchronized to LiDAR that is used to determine context and severity of near-miss LiDAR results.
Detection	Crowd Behaviour Monitoring	CCTV Camera	Captures video footage of crowds synchronized to LiDAR to monitor if spillage is due to overcrowding. Adds context to spillage and overcrowding data points.
Detection	Pedestrian-Vehicle Behaviour Analytics	CCTV Camera Analytics	Analyzes video footage to determine context and severity of near-miss LiDAR results and if real-time intervention is required in a certain area.
Detection	Crowd Behaviour Analytics	CCTV Camera Analytics	Analyzes video footage to determine context of spillage and overcrowding.
Detection	Crowd Volume	Bluetooth Sensor	Provides additional crowd density and movement direction monitoring, ensuring broader detection coverage.
Detection	Crowd Volume	Mobile Sensor	Provides additional crowd density and movement direction monitoring, ensuring broader detection coverage.
Detection	Feedback Loop Data	3D LiDAR, RFID, CCTV Camera, ticket sales, Bluetooth and Mobile sensing	Data layer that refines AI engine by comparing predicted vs real-time conditions, helping the system optimize resource allocation, determine if reallocation is required, and identify gaps in the AI engine.
Central Database	Dynamic Monitoring	Primary Warning Signs, Feedback Data	Updates daily collecting data from the detection layer.
Central Database	External Variables	Secondary Warning Signs	Combination of predetermined and real-time data on external factors that influence crowd and vehicle behaviour.
Prediction	Risk Hotspot Prediction	AI Engine	Uses the central database to predict risk twice per event cycle (before and after event).
Central Analytics Platform	Dynamic Decision Support Tool	Central Analytics Platform	Compares predicted and real-time data to recommend adaptive EMS and traffic control responses.
Tracking	Risk Visualization	GIS Dashboard	Multi-layered dashboard with AI prediction layer, real-time risk hotspots layer, crowd movement layer, event

			and emergency staff layer, and accidents/incidents layer.
Tracking	Risk Prediction VIsualization Layer	AI Engine Results VIsualization	Layer that shows AI predicted risk hotspots.
Implementation	Dynamic Risk Management	Advanced Transportation Controllers	Governed by a prediction based plan with a secondary, real-time override layer which is activated if risk threshold is persistently met. Signal phase and timings can be dynamically adjusted live data streams.
Implementation	Dynamic Risk Management	Emergency Staff	Positioned according to predictive hotspots, and may change throughout the day based on alerts from the central analytics platform.
Implementation	Dynamic Risk Management	Dynamic Message Sign	Displays pedestrian safety messages and reroutes that can be dynamically adjusted.
Implementation	Public Awareness	Google maps/User friendly app	Provides emergency alerts, recommended routes, and safety messages to the general public

Refer to Appendix B for the Systems Architecture Diagram.

5 ANTICIPATED IMPACTS

5.1 STAKEHOLDER IMPACTS

This project impacts a variety of stakeholders including:

- General Public: This category includes World Cup attendees (both visitors and local attendees), and individuals not partaking in the World Cup but travelling between roadways that overlap with World Cup activities.
- Transit Operators: The Southeastern Pennsylvania Transportation Authority (SEPTA) is the public transit network in and around Philadelphia. The network is expected to experience increased usage as Philadelphia hosts the World Cup.
- State and Local DOTs: This includes the Pennsylvania Department of Transportation (PennDOT) and the City of Philadelphia who are overseeing planning for the World Cup and will handle the traffic management and operations teams.
- Stadium Operator: The Philadelphia Eagles operate the stadium through leasing from the City of Philadelphia.
- Emergency Response Teams: Police and emergency medical services (EMS) teams will be present at the marches to respond to any incidents quickly.
- Surrounding Businesses: Businesses such as hotels, pubs, and restaurants are expected to see a surge in customers during the World Cup tournament.

Safety is enhanced during the World Cup with this system and impacts multiple stakeholders. Studies show that a significant number crowd related safety issues are a result of crowd mismanagement, with many incidents being preventable by intervening at early stages identified by real-time monitoring [3]. Thus, by focusing on proactive measures, this system is able to respond early to activity that could transpire into a real incident, greatly mitigating the risk of that incident actually occurring. Not only does this safety enhancement improve the World Cup experience for attendees but makes it easier for locals and the other individuals driving through Philadelphia to navigate the surge of visitors over the course of the tournament as the most risky areas will be identified and thus properly dealt with and communicated with the public. The public awareness component of this system gives vital information to visitors who will be less familiar with the layout of the city, controlling confusion and potential conflicts between visitors and locals. It is also beneficial to local businesses who can use the app to prepare for surges of customers by planning marketing and store operations accordingly and for them to stay up-to-date on any alerts. Furthermore, if safety is enhanced during the World Cup through this system, there is less chance for any delays or shutdowns happening, preventing lost revenues. A proactive system with the ability to see where additional resources and safety measures are required also positively impacts transit operators, who will need to navigate the challenge of busier streets and increased usage. An improvement in safety also means less strain on emergency staff and resources.

Another benefit of this system is the visualization of risk zones, allowing for a more streamlined approach for operations and emergency management teams. Being aware of emerging risks allows operations and emergency teams the chance to deploy in a targeted fashion, saving time if an incident does occur. This management optimization can lead to smoother and more efficient movement of fans, creating a more enjoyable experience for attendees overall. The visualization and AI-based prediction saves the management team time as they can clearly spot insufficiencies in the current system, saving the team time. The 2024 Olympic Games in Paris reported saving 80% in time by using digital twin simulation [21]. A similar time saving benefit could be expected using this system during the 2026 World Cup due to the predictive aspects of this system.

Following the World Cup, the City of Philadelphia will have a rich database and established network of sensors in place, which can help state and local DOTs as well as the stadium operator with crowd management at future events.

5.2 ECONOMIC IMPACTS

The cost of this system may require notable investment considering the cost of LiDAR sensors and additional CCTV cameras, the prediction and tracking infrastructure required, and the integration of the entire system. If we assume there will be two designated march routes, there are approximately 140 intersections within the two routes in the area defined by the green box highlighted in Figure 1, making full coverage detection quite expensive. However, if deployment is focused on key zones such as high risk intersections along the designated march routes, high risk intersections around the Center City, at the entry way leading up to the stadium, and roadways near some public gathering areas, this could aid in making the system more cost efficient. Despite the costs, investing in a proactive risk management strategy can provide significant economic return.

The KABCO crash unit cost amounts to approximately $160,200 [22]. In the cases of severe incidents, temporary delays can lead to lost revenue for surrounding businesses. By identifying areas of risk early on, the possibility of these incidents occurring is greatly mitigated. Furthermore, as described in section 2.4, the real-time visualization and predictive aspects of the system prevent last-minute management incident escalation, which can incur significant costs. Another factor to consider is that many emergencies are unexpected, thus present variable costs, which may be well beyond what is budgeted for. On the other hand, investing in a strong risk management system can be planned and accounted for as well as optimized if the opportunity to streamline exists.

The return on investment of this system is not only in optimization and mitigation of risks, but also in the long term benefits of the City of Philadelphia. For example, Qatar invested significantly in safety and security during the 2022 World Cup and following the World Cup, experienced a boost in tourism [23], contributing positively to the country's GDP [24]. Thus, a good experience for visitors during the World Cup could bring more economic opportunity to Philadelphia through increased tourism.

5.3 LONG TERM IMPACTS

Following the World Cup, this system can be adapted to other cities around the world for similar events. Additionally, repurposed as a day-to-day support tool for transportation planners and emergency response teams in Philadelphia. Compact LiDARs are mobile so they may be installed around the city on a rotating basis or in undermonitored areas around the city to identify risk indicators like pedestrian spillage and near misses, helping to identify gaps in a city's transportation and pedestrian safety infrastructure. Collecting this data and visualizing it, along with using the AI-engine to predict emerging risk-zones provides a data-driven way to justify infrastructure upgrades.

5.4 CHALLENGES

There are some potential challenges with this system. Firstly, there are concerns regarding data privacy. To mitigate this, clear privacy policies should be developed and communicated. It should also be anonymized, safely secured, and aggregated when possible.

Another challenge is that some CCTV cameras are live-feed only and do not have recording capabilities. Therefore, while setting up this system, each potential camera location will need to be assessed in collaboration with relevant organizations to confirm recording capabilities. An additional challenge with the CCTV cameras, as well as LiDAR sensors, is that there will be gaps in coverage as deployment will be targeted, focusing on designated routes and likely gathering areas. Although the Bluetooth and mobile sensing fills these gaps, they are less precise, particularly in the case of near-miss interactions. It can also miss demographics with cell phones such as children. Thus, additional sensors may be needed.

Furthermore, implementing the prediction layer of this system will be a complicated process. Different categories of data will have different impacts on risks and incidents. For example, rain events could have a strong impact on risk but depending on the time of day, location, and intensity, this impact can vary. Therefore, weight factors should be applied to the data to enhance this system. This will be a complex process, requiring further AI training, consideration of a range of scenarios, and a nuanced approach to create weightings that accurately reflect the impact of factors. The system could be enhanced by predicting behaviours and this is also a challenging process, as human behaviours are dynamic and context-specific.

Lastly, data such as traffic volumes and crowd behaviour from 2020-2021 are not as applicable to an event in 2026, given the COVID-19 pandemic thus, limiting the amount of past data that can be used to train the AI-engine in the predictive layer.

6 CONCLUSION

This report proposes a system of predicting and monitoring early warning signs of conflict points during fan marches at the 2026 World Cup in Philadelphia. A proactive crowd management system offers the potential to support more organized, timely, and effective responses. The system outlined in this report identifies key risk indicators such as overcrowding, pedestrian spillover, bottlenecks, and pedestrian-vehicle near-miss interactions to anticipate and mitigate risks before they escalate into incidents. The system employs a variety of ITS technologies and is designed as a continuous feedback loop, allowing real-time data and predictive analytics to work together for dynamic decision making. By the end of the 39-day tournament, this system has the potential to transition to a component of Philadelphia's daily transportation operations and can be adapted for other cities and events.

7 ADDITIONAL RESOURCES

See [25] for locations of existing CCTV cameras in Philadelphia. See [26] for creating a model of individual pedestrian interactions with a crowd. This source can be used to develop criteria for pedestrian spillage detection. Example criteria could be to combine factors such as the number of individuals outside designated pedestrian areas, the length time spillage lasts, and if spillage is due to overcrowding. See [27] for crowd management strategies used during the 2022 World Cup in Qatar.

APPENDIX

A. Tables

Table A.1: *Summary of Database*

PRIMARY WARNING SIGNS			
Warning Sign	**Data Source**	**Description**	**Recommended Update Frequency***
Pedestrian-Vehicle Near Miss Incidents	3D LiDAR with CCTV video analytics	Near miss incidents are a vital indicator that an area has the potential of experiencing an actual accident, especially if the near miss is repeated. Thus, an area will be flagged for review if there is a single near miss there and the threshold for flagging a near-miss hotspot will be 2 or more near misses in the same general area. Sensors will detect for close pedestrian-vehicle interaction as well as evasive movements. These are more likely to occur during impromptu marches, at the beginning locations of organized marches, at the edges of march routes, and pedestrian movements around the city. AI-based video analytics will analyze the associated CCTV video for context and severity to determine if an intervention is needed. The severity threshold will be based on frequency, the nature of the near miss, and whether it occurs at a high risk location. If a near miss is simply flagged, it will be reviewed by staff post-event to inform future strategy, but if it meets the severity threshold, it will trigger a real-time alert and feed into the central analytics platform, which is discussed in detail in 3.1.3.	Real-time data layer on GIS map
Crowd Spillage into Vehicular Areas	3D LiDAR with CCTV video analytics	Crowd spillage into vehicular areas increases the risk of pedestrian-vehicle conflicts. LiDAR sensors will detect pedestrian volume exceeding designated areas and spilling onto vehicle zones. This will be more relevant in areas with less crowd and vehicle separation, likely at the beginning of march routes, transition points, and at transit hubs. LiDAR is the ideal sensor for this as it is able to track pedestrian and vehicle boundary lines and can track when spillage occurs. See Table 2 shows an example for crowd spillage thresholds. CCTV video and analytics will provide context for the spillage to ensure it was due to overcrowding or if it was due to alternate factors such as unexpected pedestrian behaviour.	Real-time data layer on GIS map
Overcapacity of March Space and Emerging Bottlenecks	3D LiDAR and Bluetooth/mobile sensing**	Overcrowding in spaces can lead to trampling, spillage into vehicular areas, bottlenecks, and can impede emergency responses [28]. Marches are expected to be quite crowded thus, LiDAR sensors on designated march routes will mainly detect for bottlenecks and abnormal surges during organized marches. Overcrowding in areas outside of designated march routes and outside organized march times will also be detected through mobile sensing, ensuring broad spatial coverage. See Appendix A.2 for criteria of overcrowding.	Real-time data layer on GIS map
SECONDARY VARIABLES			
Warning Signs	**Data Source**	**Impact on primary data results**	**Recommended Update Frequency**
Weather Conditions	Weather API	Weather events can impact pedestrian and driver behaviours so the predictive layer must account for this influence. The main weather conditions would be: • rain events ▫ decrease in pedestrian driver visibility ▫ slower movements • temperatures > 27ºC/80ºF are considered cautionary by experts [29] ▫ temperature that causes behavioural shift ▫ people more likely to congregate indoors or seek shade and gain lower tolerance to walking • mild/normal temperatures ▫ weather not expected to be a major contributor to primary warning sign results	Hourly for minor deviances from prediction, immediately for major unexpected weather events or major deviances
Event Timings	Event Management System	Event timings for pre-planned events give context to crowd surges. Delays, rescheduling, or overlapping events are also important to account for as they can cause shifts in pedestrian and vehicle behaviour and expected volumes.	If any deviations from planned timings occur
Time of Day	External Time API	Different times of day impact pedestrian and vehicle volume peaks.	N/A
Land Use	City Operation and event management information	Any reduction or change of space allocated to marches and pedestrians can impact how crowds form and move during marches and around the city.	If any changes occur
Transit Station Volume	Bluetooth/mobile sensing** and transit scans	Higher volume at transit stations could indicate a possible crowd surge.	Hourly
City-Wide Historic Traffic Volumes	From PennDOT (2022-2025)	Historic traffic volumes will be used for prediction. Traffic volumes can predict things such as congestion which slows foot traffic and can cause crowd surges where people are joining a march. It can also help predict possible conflict points for impromptu marches.	N/A
City-Wide Real-time Traffic Volumes	Traffic Flow API (TomTom Traffic Index or Waze)	Real-time traffic volumes will be used in the real-time GIS dashboard layer to keep the system adaptive and dynamic.	Real-time on GIS map
FEEDBACK LOOP DATA			
Data	**Data Source**	**Description**	**Recommended Update Frequency**
Mismatch between predicted and real-time hotspots	Combination of all data sources	If the real-time data produces hotspots that differ from the AI model prediction, this can be used to further train and refine the AI engine. Furthermore, if significantly different, this new data may override the corresponding prediction data, allowing the GIS map to update and recommend reallocation of resources based on real-time tracking.	Real-time data layer on GIS map
Event and Emergency Staff movements	RFID	This data provides information on staff location, staff response time, and can provide feedback on resource allocation through analysis. This data provides the AI engine with patterns to recognize and reorganize staff deployment if necessary.	Real-time data layer on GIS map
Accidents or Incidents	3D LiDAR, CCTV video analytics, reporting by event staff and/or witnesses	Accidents or incidents resulting in injury or response team deployment will be recorded by event staff. This data may validate if warning sign data accurately predicted the incident location. It also can help identify a high risk area.	Real-time data layer on GIS map when incident/accident is reported by staff and entered into system
Event Attendees	Ticket sales, 3D LiDAR	Volume of event attendees will help estimate the predicted crowd and can train the AI-based model. The ticket sales provide an estimation while 3D LiDAR results provide real-time monitoring to get an accurate representation of crowd size.	Real-time data layer on GIS map

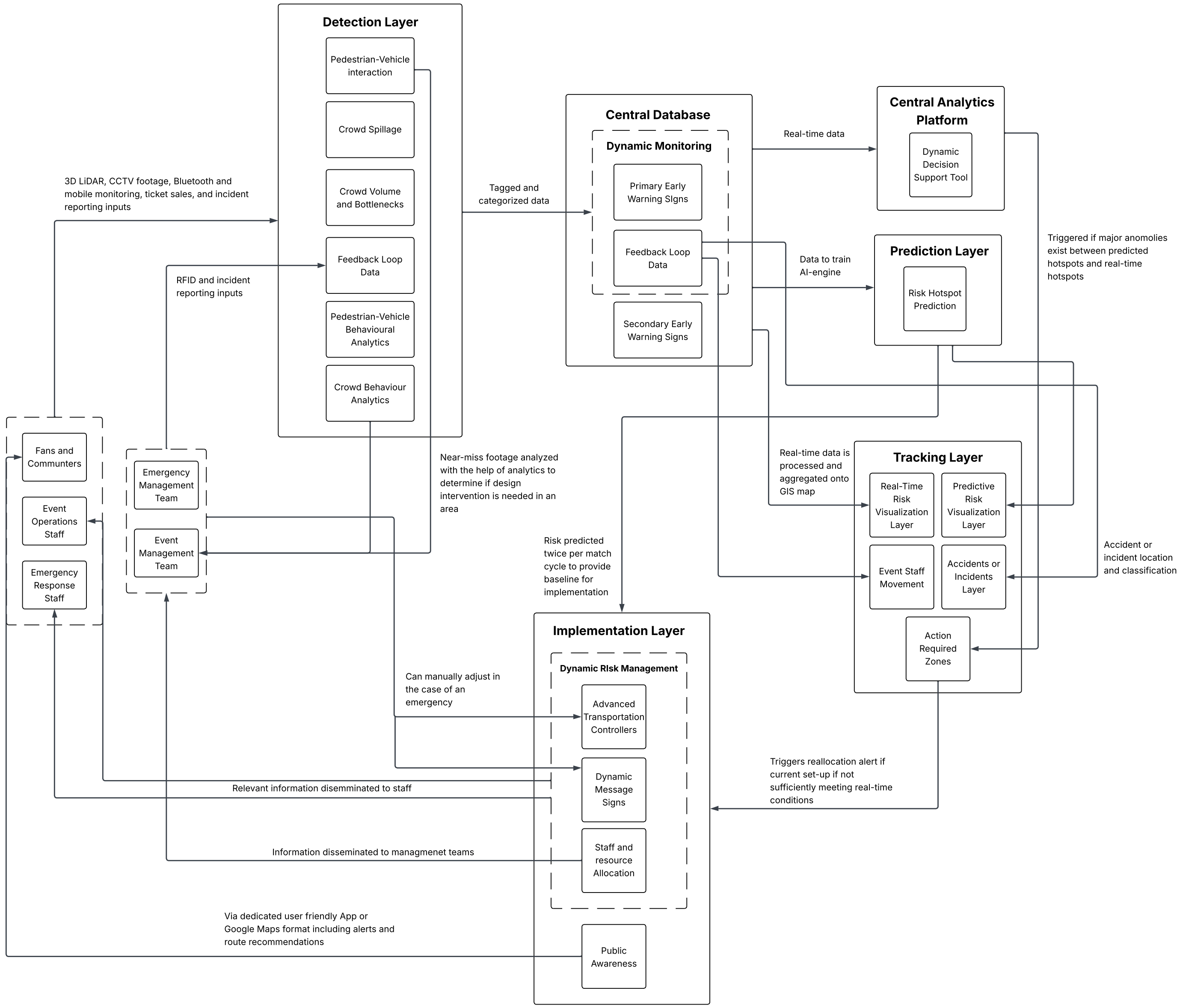
*Predicted hotspots at the beginning of the day will be based on predictions made given the previous day's data. And for the first day/match, using the baseline situation. However, there is a possibility of real-time results mismatching with the predicted results. Thus, data will be updated at certain points throughout the day to show real-time emerging risks.

**Anonymity is a concern for cellular monitoring. However, this system is measuring crowd surges and general movement patterns thus aggregated datasets will be used which maintain anonymity.

Table A.2: *Overcrowding Criteria according to [30]*

Density (persons/m^2)	Pedestrian Behaviour and Risk	GIS Label
< 1	Pedestrians have freedom to choose walking speed and path; minimal interference	Free movement
1 to 2	Moderate interaction; comfortable movement with occasional adjustments	Comfortable crowding
2 to 4	Movement slows; limited ability to bypass others; increased physical contact	Dense Crowd
>4	Movement severely restricted; high risk of spillover and pedestrian conflicts; dangerous conditions	Overcrowding (critical density)

B. Systems Architecture Diagram



REFERENCES

[1] Transport Canada, "Intelligent Transportation Systems," Jul. 25, 2024. [Online]. Available: https://tc.canada.ca/en/road-transportation/innovative-technologies/intelligent-transportation-systems

[2] A. Lesani, "Beyond the Close Call: Solving Near-Miss Detection with 3D LiDAR," *Ouster*, Oct. 16, 2024. [Online]. Available: https://ouster.com/insights/blog/beyond-the-close-call-solving-near-miss-detection-with-3d-lidar

[3] M. Haghani, M. Coughlan, B. Crabb, A. Dierickx, C. Feliciani, R. van Gelder, P. George, N. Hocaoglu, S. Laws, R. Lovreglio, Z. Miles, A. Nicolas, W. J. O'Toole, S. Schaap, T. Semmens, Z. Shahhoseini, R. Spaaij, A. Tatrai, J. Webster, A. Wilson, "A roadmap for the future of crowd safety research and practice: Introducing the Swiss Cheese Model of Crowd Safety and the imperative of a Vision Zero target," *Safety Science*, vol. 172, p. 106176, Oct. 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0925753523002345

[4] Morris & Dewett Injury Lawyers, "Crowd Surges: Causes, Risks and Prevention," *Morris & Dewett*, Jan. 2025. [Online]. Available: https://morrisdewett.com/crowd-surge/

[5] Pennsylvania Department of Transportation, *Philadelphia County Traffic Volume Map*, Sep. 2024. [Online]. Available: https://gis.penndot.pa.gov/BPR_PDF_FILES/MAPS/Traffic/Traffic_Volume/County_Maps/Philadelphia_tv.pdf

[6] Lincoln Financial Field, "FAQs," [Online]. Available: https://www.lincolnfinancialfield.com/faqs/#:~:text=By%20Public%20Transportation,last%20southbound%20stop%2C%20NRG%20Station.

[7] Southeastern Pennsylvania Transportation Authority, "City Council Hearing 2026 Preparedness," Apr. 14, 2025. [Online]. Available: https://wwww.septa.org/news/city-council-hearing-2026-preparedness/

[8] Elite Sports Tours, "How to Get to Lincoln Financial Field for Philadelphia Eagles Games," *Elite Sports Tours*, Oct. 2024. [Online]. Available: https://blog.elitesportstours.com/post/how-to-get-to-lincoln-financial-field-for-philadelphia-eagles-games

[9] L. Miranda, "Pedestrian islands are coming to Chestnut Street in West Philly," *WHYY*, Apr. 1, 2025. [Online]. Available: https://whyy.org/articles/pedestrian-islands-chestnut-street-west-philly/WHYY

[10] City of Philadelphia, "LiDAR-LAS data," *OpenDataPhilly*, Apr. 2022. [Online]. Available: https://opendataphilly.org/datasets/lidar-las-data/OpenDataPhilly

[11] Urban Engineers, "South Broad Street Intersection Modifications," *Urban Engineers*, 2024. [Online]. Available: https://urbanengineers.com/projects/south-broad-street-intersection-modifications

[12] City of Philadelphia, "City of Philadelphia Disability Characteristics Map," *ArcGIS Map Series*, [Online]. Available: https://phl.maps.arcgis.com/apps/MapSeries/index.html?appid=2a51d5357e24439996f2aa9cdeae72b9

[13] Pennsylvania Department of Transportation, "Broad Street Safety Improvements," *Commonwealth of Pennsylvania*, [Online]. Available: https://www.pa.gov/agencies/penndot/projects-near-you/district-6-projects/broad-street-safety-improvements.html

[14] Health and Safety Executive, *Managing Crowds Safely: A Guide for Organisers at Events and Venues*, 2nd ed., Sudbury, UK: HSE Books, 2000. [Online]. Available: https://www.hse.gov.uk/pubns/indg142.htm

[15] D. Helbing, A. Johansson, and H. Z. Al-Abideen, "Dynamics of crowd disasters: An empirical study," *Phys. Rev. E*, vol. 75, no. 4, p. 046109, Apr. 2007, doi: 10.1103/PhysRevE.75.046109.

[16] A. Lesani, "From inductive loops to LiDAR: How LiDAR-powered traffic systems are redesigning urban traffic management and safety," *Ouster*, Feb. 19, 2025. [Online]. Available: https://ouster.com/insights/blog/inductive-loops-to-lidar-how-lidar-powered-traffic-systems-are-redesigning-urban-traffic-management-and-safety

[17] Abley, “Using LiDAR in transportation planning and engineering,” *Abley*, Apr. 2024. [Online]. Available: https://abley.com/our-insights/lidar-in-transportation-engineering

[18] Y. Jiao, J. Li, J. Wu, D. Hong, R. Gupta, and J. Shang, "SeNsER: Learning Cross-Building Sensor Metadata Tagger," in *Findings of the Association for Computational Linguistics: EMNLP 2020*, pp. 950–960, Nov. 2020. [Online]. Available: https://aclanthology.org/2020.findings-emnlp.85.pdf

[19] OnePlan, "VenueTwin: Create a hyper-realistic version of your real venue," [Online]. Available: https://www.oneplan.io/venue-twin/

[20] J. Moffitt, "Real-Time Anomaly Detection: Use Cases and Code Examples," *Tinybird*, Apr. 1, 2024. [Online]. Available: https://www.tinybird.co/blog-posts/real-time-anomaly-detection

[21] OnePlan, "Paris 2024: The Digital Twins being used to plan the Olympic and Paralympic Games," OnePlan.io, 2024. [Online]. Available: https://www.oneplan.io/case-studies/paris-2024-olympics-digital-twins/

[22] Massachusetts Department of Transportation, "Crash Costs for Highway Safety Analysis," Mass.gov, 2024. [Online]. Available: https://www.mass.gov/info-details/crash-costs-for-highway-safety-analysis

[23] Bloomberg, "Qatar to ‘Liberate’ Tourism Sector to Extend Post-World Cup Boom and Bring in More Tourists," *Hindustan Times*, May 14, 2024. [Online]. Available: https://www.hindustantimes.com/lifestyle/travel/qatar-to-liberate-tourism-sector-to-extend-post-world-cup-boom-and-bring-in-more-tourists-101715670709953.html

[24] International Monetary Fund, "Economic Diversification in Developing Countries," *IMF eLibrary*, 2024. [Online]. Available: https://www.elibrary.imf.org/view/journals/087/2024/006/article-A001-en.xml

[25] Pennsylvania Department of Transportation, "View Live Pennsylvania Cameras," 511PA, 2025. [Online]. Available: https://www.511pa.com/cctv?start=20&length=10&order%5Bi%5D=4&order%5Bdir%5D=asc

[26] D. Helbing and A. Johansson, "Pedestrian, Crowd and Evacuation Dynamics," in *Extreme Environmental Events: Complexity in Forecasting and Early Warning*, S. A. B. (Ed.), Springer, New York, NY, 2011, pp. 697–716, doi: 10.1007/978-1-4419-7695-6_37.

[27] Cisper Electronics B.V., "Case Study: Managing millions of fans at the FIFA World Cup Qatar 2022 with RFID," 2022. [Online]. Available: https://www.cisper.com/en/case-studies/case-study-managing-millions-of-fans-at-the-fifa-world-cup-qatar-2022-with-rfid

[28] Arnold & Itkin LLP, "What Makes Crowds Dangerous?," *Arnold & Itkin LLP*, [Online]. Available: https://www.arnolditkin.com/blog/concert-injuries/what-makes-crowds-dangerous/

[29] Occupational Safety and Health Administration, "Exposure to Outdoor and Indoor Heat-Related Hazards," OSHA Publication 4185, 2022. [Online]. Available: https://www.osha.gov/sites/default/files/publications/OSHA4185.pdf

[30] J. J. Fruin, *Pedestrian Planning and Design*, New York, NY: Metropolitan Association of Urban Designers and Environmental Planners, 1971.