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Estimated Total Stadium Emergency Evacuation's Time Based on Existing Population Analysis

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Keywords

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Pedestrian Dynamic,
Stadium.

Abstract

The problem of evacuation from stadium during catastrophic event is a vital research field which should be considered more deeply.This research provides mathematical calculations for analysis of evacuation from stadium. Using these calculations leads to the evacuation path optimization. Evacuation models are made based on some advanced integrated algorithms and using parameters of population movement characteristics. The recognition of evacuation parameters is vital for each methods of evacuation. In this way, the total evacuation time based on the variables which affect the emergency evacuation of the Naghsh-e- Jahan Stadium in Isfahan, Iran is calculated with pedestrian dynamic software.

1. Introduction

The various collective catastrophic events observed in pedestrian crowds have recently became vital research field and attractred many scientists. These events may lead to a waste of time for evacuation in normal pedestrian behavior or may put safety of the pedestrian in danger for panic pedestrian behavior. When facing such uncertainty, it is crucial to have robust rescue management and evacuation strategies that are able to cope with these and other kinds of complications, to avoid severe losses of human lives [1].

Since the 90s, the construction of sports stadium vastly has been improved in shape of stadium, or the quality and capacity. Necessity of the modern stadiums due to large-scale international events like Olympic or world cup Games, is obviously can be seen in the recent years [2].

Modern stadiums by increasing the size of the venue and the evacuation's facilities and strategies can be responsive for these large scale events. For these modern stadiums accident like fire would be super dangerous with these amount of crowd and for evacuation of pedestrian all the safty aspect should be considered. Not only in panic situation pedestrian should be easily evacuated from stadiums but also in normal case it is expected the evacuations' facilities are designed for the minimum evacuation time and wase of time [3, 4].

Potential of casualties in evacuation from stadiums are mainly function of density of crowd, geometry of the outlets' corridors and outlets' doors. This fact can be seen in FIFA records that between 1913 and 2000 there are 23 casualties worldwide and the total death is at least 1380 [5-8].

In accidents like fire pedestrian harshing, panic, high density and crowd shaking phenomenon will be appeared, all these issues may raise potential of casualties and also cases like crowd riots result in same way [9]. Therefore, researching on stadiums evacuation has important and practical significance, and it is always the hot point in the research field of public safety [10].

It is clear that to solve evacuation problem, first of all the dynamics of human crowd should be model, and in this modeling all the parameters that influence in evacuation should be considered.

For system consisting of many similar entities, and interactions between these entities under specific condition can lead to calculating dynamic of the system. In these systems pattern of the systems behavior is collective behavior [11]. An important aspect of collective behaviour is that the dynamics of a single entity is dominated by the influence of the other entities and that behaviour therefore can be radically different from what one would observe when the entity is left on its own. Two types of entities can be assumed living, "self-propelled" entities and non-living entities, such as molecules or self-propelled particles, both of these two type entities can exhibit collective behavior [12].

Human crowds of sufficiently high density exhibit features of collective behaviour, such as arching near bottlenecks [13, 14], stop-and-go waves evolving into turbulence [15], lane formation, and freezing by heating [16].

In more deep research crawd modeling, classified in three different types, (a) Fluid dynamical models in which usually neglect the description of individuals altogether, (b) Particle

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models the dynamics of the particles is either determined by forces that reflect various physical, social, and psychological influences, or through ruled-based algorithms that consider the local distribution of particles. The former is known as social force models [16-18],while the latter approach is most commonly applied in relation to so-called cellular automata models. (c) Agent-based models, in this case the entities were modeled as agents and the complexity in the modelling of individuals has been increased, the social intraction effects on internal state of the agents. Agent-based models can be seen as an extension to the social force approach [19], rely on rule-based action [20], or be some kind of combination of the two [21]. In this regard, many features of these three general methods, like flexibility, extensibility, efficiency, scalability, accuracy and robustness are evaluated by several researchers [22].

Also many researcher improve the above three general models for example; Helbing et. al proposed “helbing social force model” which criticized for over-simplifying the problem [14-17]. The floor field cellular automata (CA) model is a discrete rule based model which can find the shorter path to the target location with models of interactions with other agents and with infrastructures. CA model is inspired from motion of ants [23]. The publicly and freely available simulation software combines Fire dynamics simulator [15], a computational fluid dynamics solver for modelling fire-driven fluid flow, with an agent-based egress calculation model for evacuation [24-26]. Also there are some other crowd dynamics models like cognitive heuristics model which is base on a cognitive science approach [27], PLEdestrians: A least-effort formulation which is base on the approximation that a person’s caloric expenditure. The Epstein civil violence model have either represented normal behaviour scenarios such aspedestrian traffic applications or evacuation scenarios where the motivations and goals of agents are clearly define, The Jager approach-avoidance model is a rule-based simulation model which is used to study clustering and fighting in two-party crowds. With this background for crawd dynamics some software for modeling of crawd dynamics are developed such as; Legion software which combines two-dimensional simulations with two- or three-dimensional visualization. The agents move through the environment according to the principle of least effort, with minimal time, minimal costs (dissatisfaction and discomfort), minimal congestion and maximum speed [28-31]. Myriad II software combines methods for network analysis, spatial analysis, and agent-based analysis into one modelling suite. MassMotion software which is again agent base software,has been developed to be a generalized pedestrian simulator. Massive is well-known as a crowd simulation software in which the agent dynamics is controlled by fuzzy logic in combination with a library of pre-programmed manoeuvres which makes the agents respond to sight, hearing, and touch [32, 33].

In this research respect to the all referred past studies, evacuation models are maded base on some advanced integrated algorithms and using parameters of population movement characteristics for the Naghsh-e- Jahan Stadium in Isfahan, Iran. The total evacuation time from the stadium based on the variables that affect the emergency evacuation is calculated, and the optimum paths of evacuation are also proposed, through using Pedestrian dynamic software.

2. The Naghsh-e- Jahan Stadium Parameters

The Naghsh-e- Jahan stadium is located in the north of Isfahan and adjacent to the forest park between Isfahan and Dawlat Abad, Figure 1. The natural grass land is a collection with a drainage area of 11000 meters. This stadium is the second largest stadium in Iran. The stadium is a multifunctional stadium and with capatity of 75000 people in two floor, capacity of the first floor is about 42000 people and capacity of the second floor is about 33000 people, stadium is oval shape in both floor, The total area of the stadium on the platform is 103250 square meters. There are four separate entrances for this suite, including: entrances to the spectators, office space and special place. Figure 2 shows entrance 4 to the special place. Figure 3 shows entrance 2 and 3 for the spectators, office space [34]. Figure 4 shows plan of the stadium and four entrances.

Figure 1. The Naghsh-e- Jahan stadium [34]

Figure 2. Entrances to the stadium [34]

Figure 3. Entrances to the stadium [34]

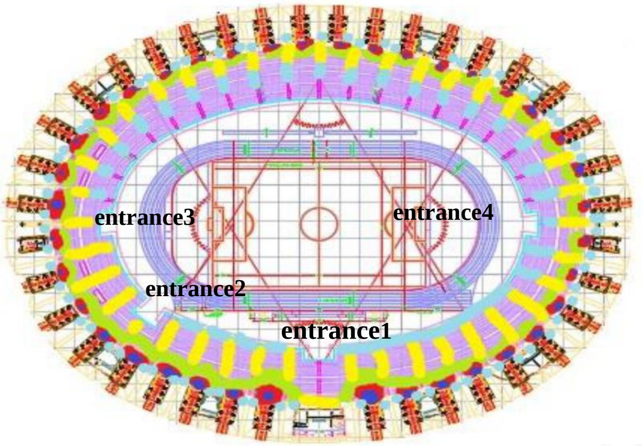

Figure 4. Four separate entrances to the stadium [34]

2.1. Scenarios for Evacuation Simulation

The proposed approach to develop an evacuation route would produce optimal solutions based on the simulation results for proper evacuation plans. The models and simulations were categorized based on the number of evacuees. Particularly, there are 10000, 25000, and 75000 evacuation scenarios respectively, for the audience groups of 10000; 25000; 75000, people. For each of these scenarios simulation generated a different evacuation process, which was best for that situation. The algorithm should control minimum bottleneck in the shortest path. For the evacuation simulation the seats were divided in to genral subgroups as it exsit in he stadium.

3. Main Aims of Simulation

The main aim of this research is to calculate T_{tet} (total evacuate tme) for each evacuation scenario. The simulation software calculated the capacity of the exits, crowd density, T_{tet}, and shortest cleared path (SCP). Pedestrian dynamics software automatically generated the calculations for T_x (time take to reach to an exit), C_x (capacity of exits), V_x (volume of the crowd in an exit), and SCP for every phase of the project.

4. General Modeling in Pedestrian Dynamics Software

The development of the system of the Pedestrian dynamic involves the drawing of the stadium, the moving behaviors, and path calculating. The beginning of the project is to identify the geometric physical data of the design of the stadium. The software automatically generates the access route and walking area during the compile process. The entry and exit have to be defined manually according to the physical design of the stadium. There is a special feature in Pedestrian dynamics, which is to enable agent to identify where to show up and disappear. The next step is to change the parameters such as the number of evacuees, walking speed, and the distribution method of crowd according to the simulation scenarios. In the third step, the simulation is performed 10 times per scenario to make sure the accuracy of the results. Finally the system generates the reports to identify the crowd behaviors in the stadium, such as density area, time taken to evacuate, where the crowd bottleneck occurs, etc.

5. Algorithm used in Pedestrian Dynamic Software

Algorithm to calculate time and path of evacuation in pedestrian software is base on a cost function which should be minimized. The cost function used to compute the evacuation path of the crowd is obtained as in Eq. (1)

$$\alpha \int_{p} ds + +\beta \int_{p} dt + \gamma \int_{p} gdt \quad (1)$$

where ds means that the integral is taken with respect to path length. dt means the integral is taken with respect to time. The letters of α, β, γ are constants for the equation [34]. The first phase ($\alpha \int_p ds$) describes the path how path length effect to the evacuation. $\beta \int_p dt$ solves the time of an evacuation and $\gamma \int_p gdt$ means the discomfort level in an evacuation. If this three phase (which are distance, time and discomfort level) in above cost function minimize simultaneously the optimized path for evacuation will be calculated.

The total time of evacution (T_{tet}) for spectator to exit from the stadium is stated in Eq. (2)

$$T_{tet} = 1/(f_p B') * (N_a - N) + K_s/V \quad (2)$$

where the f_p is moving rate from an exit, B' is the width of the exit door, N_a is total number of evacuees. N is who can escape, which can be expressed in terms of the flow rate of people moving from the stadium [34]. K_s is the distance to the location of first evacuee. V is the speed of the evacuee.

So as it is described in above Pedestrian dynamic use Eq. (2) to calculate the total evacuation time, then with this total evacuation time and Eq. (1) it finds the shortest path to evacuate.

6. Assumption and Results of Simulation

Pedestrian dynamics uses the triangular distribution for the speed variable of the algorithm (TRI (0.5, 1.75, 0.86)). The 0.5 meters per second is the average walking speed of pedestrian on stairs. The speed of 1.75 meters per second is the average walking speed of pedestrian on ground. The speed of 0.86 meter per second is the average pedestrain moving speed [23]. In this research, normal distribution was used to get more accurate walking speed for the simulation: (NOML (1.15,0.2)). The used μ as 1.15 and σ as 0.2.

Results of the three assumed scenarios indicate that the T_{tet} varies from 5:58 minutes to 21:00 minutes based on number of evacuees. Figure 5 shows the results for scenario 10000 people evacuation. The results show that the total evacuation time varies in between 5:52 and 6:08 minutes. The average response time is 23 seconds. According to the data, a person could evacuate the facility within 23 seconds if the occupant is first floor and near the entrances of the stadium. People from the members' area could take more time to evacuate because of the seat layout and the design of the stadium.

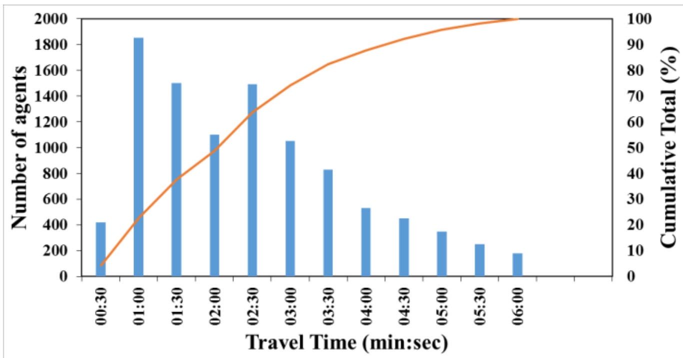

Figure 5. Evacuation behavior in 10000 people evacuation

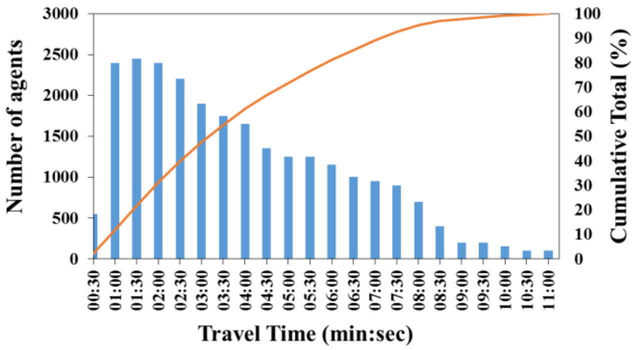

Figure 6. Evacuation behavior in 25000 people evacuation

According to the Figure 6, the T_{tet} for 25000 people evacuation scenario is $10:54$ minutes. The mean of the T_{tet} is $3:21$ minutes. The average evacuation time is 4:23 minutes in 25000 people evacuation scenario. It's interesting that nearly 50% of the crowd evacuate during seventh minutes of the evacuation.

Figure 7 shows the results for scenario 75000 people evacuation. The results show that the total evacuation time varies in between $20:48$ and $21:13$ minutes. It is always critical and challenging when evacuating a full stadium. The capacity of the main pavilion of Naghsh-e- Jahan stadium is up to 75000 individuals.

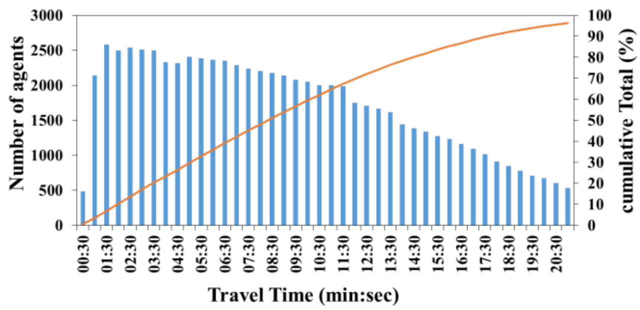

Figure 7. Evacuation behavior in 75000 people evacuation

The audience may reach to the full capacity of the stadium in events such as home coming. Unlike other scenarios, in the 75000 people evacuation, there are more interactions of crowd and exits routes. Also from Figure 7 it can be concluded evacuation rate is saturated with rate of 5700 P/min^{-1}.

Figure 8 shows the total evacuation time for three scenarios.

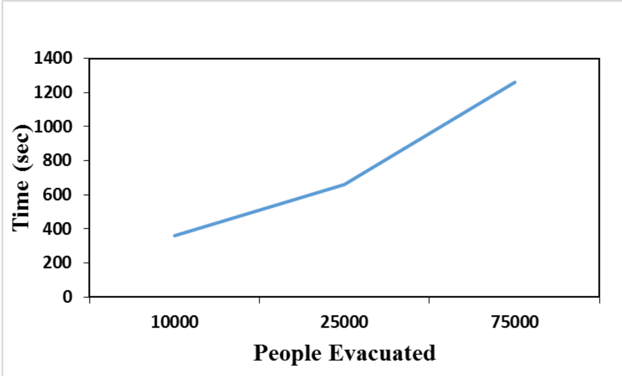

Figure 8. Total time of evacuation for different scenario

7. Conclusion

To investigate and improve the evacuation plans of the stadiums, this research has proposed empirical simulations to predict population behaviors for population evacuation scenarios based on the Pedestrian dynamic multi-agent software solution. The model simulates the characteristics, laws, regulations and population evacuation standards. The simulation model was able to change dynamically for local conditions. This model can generate valuable statistical graphs of population dynamics. It provides data such as demographic bottlenecks, population density, and average population speed. The content of this manuscrip allows the analysis of population debris in the stadium. The results of the study showed a significant change in the evacution time when the number of population increased. The danger of population congestion is high in events such as games of the derby and confrontation with Esteghlal and Persepolis teams and in national matches when seventy thousand spectators occupy the stadium. The simulation results showed that about 21 minutes of time needed to evacuate the entire population from the stadium building. Using a histogram or density mapping, a population bottleneck in the region could be determined by accumulation. According to observations, access routes and stadium outlets have enough space to evacuate the population from the building. But some places, such as stairs to access platforms, can easily be blocked during discharge at full scale. The study showed that the simulation results reflect the actual discharge in the role of the universe at an approximate level.

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