A simple model for panic driven motion in a refugee camp*

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The increasing number of refugees due to natural and man-made disasters presents significant challenges, particularly in ensuring the safe and efficient distribution of food in refugee camps. Panic-driven motion during food distribution often leads to overcrowding, collisions, and fatalities. In this study, we model the food distribution process using a crowd dynamics framework to analyze how movement patterns contribute to injuries and deaths. Our simulations show that as food distribution begins, refugees rush toward the food distribution point, leading to high-density congestion and dangerous interactions. We explore strategies to mitigate these risks by introducing fixed obstacles near the food distribution point. The results demonstrate that a single obstacle can reduce fatalities by approximately 15%, while an optimized two-obstacle configuration achieves up to a 70% reduction. Additionally, we examine the impact of varying obstacle parameters—such as size, placement, and gap distance—and discuss their effects on crowd flow. The findings suggest that strategic obstacle placement can significantly improve safety, offering a practical and low-cost intervention for refugee camps. Future work could explore additional measures, such as increasing the number of food distribution points, to further enhance efficiency while addressing logistical constraints.

INTRODUCTION

The natural calamities are increasing due to the effects of climate change. One of the unfortunate outcomes of natural calamities is the millions of humans who lose their homes and their livelihoods and have to shift to refugee camps. One of the big challenges for the rescue workers is to provide food and water to a refugee who might be starving for days. Once the food arrives in the refugee camps in the initial days of the disaster, all the refugees flock in to get the food and water for themselves as well as their family. As every refugee need to acquire the food packet as quickly as possible, panic sets in. These panic or emergency situations cause these refugees to be impatient, which results in competitive and pushing behavior[21]. This ultimately causes the refugees to suffer fatal injuries.

Here we would like to clarify the usage of the term "panic." In this paper, we have defined it as situations where high crowd density and limited egress time cause impatience, leading to competitive and pushing behavior. This differs from the social science perspective, which associates panic with emotional arousal and irrationality. There are two main features of panic-driven motion [8], they are faster than normal and tend to push each other to secure the food packet. The pushing causes the refugees to sustain injuries and they act as a hurdle and tend to slow down the crowd movement. Recent stampedes during food distribution highlight the risks of overcrowding. In 2024, ten people died at a church-organized Christmas event in Abuja, Nigeria[5], while in 2023, a Ramadan food distribution stampede in Karachi, Pakistan, left 11 dead[1]. These incidents underscore the need for effective crowd management to prevent such tragedies.

In the present work, we use the model proposed by Helbing [7, 8], where crowd behavior in panic situations is modeled. It is an improved version of the Social Force Model (SFM) and we chose it due to its significant advantages over other models such as the Cellular Automaton[4] and Agent-Based models[18]. Discrete models like the Cellular Automaton rely on the Von Neumann configuration, which limits movement options to four directions (up, down, left, and right) [2]. This constraint can force evacuees to take longer, indirect paths, increasing the time and distance to exits, especially those on opposite sides. In contrast, the SFM treats pedestrian interactions as continuous forces, providing greater flexibility and accuracy in simulating realistic movement patterns. It accounts for both physical and psychological interactions among individuals, enabling it to reproduce self-organization phenomena like arching, lane formation, and strip formation. These characteristics make the SFM particularly well-suited for modeling crowd dynamics in complex evacuation scenarios.[23]

The improved SFM from Helbing's work demonstrated that in a panic situation, even though people tried to move faster, they eventually moved slower, a phenomenon described as the 'faster is slower' effect. [7, 8]. However, recent studies have challenged this concept, demonstrating that the relationship between speed and evacuation efficiency depends on the level of competitiveness within the crowd[21]. Experimental validation by Garcimartín et al.[6] showed that in low-competition scenarios, a "faster-is-faster" effect can prevail, where increased speed improves evacuation efficiency. However, in highly competitive conditions, the traditional "faster-is-slower" effect dominates due to excessive crowd pressure and obstruction. As our model focuses on panic-driven scenarios characterized by high competitiveness, the faster-is-slower effect is expected to be the prevailing phenomenon.

Building on Helbing's model, Braun et al.[3] explored how different agents influence collective crowd behavior. Their study examined movement in complex environments, the role of spatially distributed alarms, and how virtual agents perceive and react to emergencies, adapting their individual behaviors accordingly. Jun Zhang et. al performed a real-life experiment in a classroom setting [24] and compared their results with the model results. To mimic the real-life situation, some people tried to incorporate the psychological model in the crowd dynamics [17, 20]. In this model, people found the shortest path to the exit in an emergency situation instantaneously.

Ensuring quick and efficient evacuation from public spaces is crucial, as even slight delays can drastically reduce the chances of survival [7]. Helbing et. al. [7] proposed that positioning an obstacle, such as a column or barrier, slightly off-center near an exit could actually help people escape faster during panic situations. The obstacle was believed to absorb the crowd's physical pressure and break up temporary blockages at the exit, potentially reducing the risk of trampling and stampedes. This slight asymmetric placement of obstacle has been further studied and has been shown to improve crowd outflow [11][12].

Following this, numerous studies have investigated the effect of obstacles near exits on evacuation efficiency. For instance, Jiang et al. (2014)[10] conducted experiments with college students to evaluate the impact of obstacles near exits, comparing scenarios with one, two, and no obstacles. The findings suggested that placing two obstacles near an exit was more effective than having one or none. However, this study did not systematically explore the effects of horizontal offsets, obstacle shape, or size on pedestrian flow.

In this paper, we will model the situation arising in a refugee camp, during the distribution of the food packets, where panic sets in. Here, we assume that all the refugees are randomly distributed in space around the food distribution point, and they will rush towards the food pushing among each other, which will result in injuries. We will also propose a simple strategy using obstacles by which we can reduce the number of injured refugees during this panic-driven motion.

MODEL

We have used the Helbing model of panic-driven motion [7, 8] where we assume N refugees to be spheres. An i^{th} refugee will have a mass m_i and is randomly distributed in a 2 dimensional box of length L. These refugees will initially move towards a point P_0 situated midway on a wall of the simulation box, which is assumed to be the food distribution point. The equation of motion for each refugee is given by

$$m_i \frac{d\vec{v_i}(t)}{dt} = m_i \frac{v_i^0 \vec{e}_i^{\,0}(t) - \vec{v_i}(t)}{\tau_i} + \sum_{i \neq j} \vec{f}_{ij} + \sum_{W} \vec{f}_{iW} \quad (1)$$

where $\vec{v_i}(t)$ is the velocity of the refugee at an instance and $\tau_i = 0.2 m/s^2$ as put forward by Helbing et. al [8]. The mass of each refugee is normally distributed around $m_i = 80kg$.

The refugees are given a directional velocity of magnitude $v_0^i = 1.5m/s$. This choice is based on empirical observations that associate different walking speeds with varying levels of urgency. Prior studies indicate that relaxed, normal, and nervous walking speeds are typically around 0.6 m/s, 1.0 m/s, and 1.5 m/s, respectively (Helbing et al., 2000 [8]; Helbing and Molnár, 1995 [9]; Li et al., 2015 [19]). While pedestrians in high-density, panic scenarios may not always achieve their intended walking speed due to spatial constraints and crowd interactions (Lakoba et al., 2005 [14]; Weidmann, 1992 [22]), $1.5m/s$ remains a reasonable estimate for individuals navigating a crowded but actively moving environment.

The direction given is $\vec{e}_i^{\,0}(t) = \frac{\vec{P_0} - \vec{r_i}(t)}{|\vec{P_0} - \vec{r_i}(t)|}$, where $\vec{r_i}(t)$ is the instantaneous position of the i^{th} refugee. The refugee will experience two kinds of interaction forces, one is a repulsive force experienced by the i_{th} refugee with the j_{th} refugee

$$\begin{aligned} \vec{f}_{ij} = A_i \exp(\frac{r_{ij} - d_{ij}}{B_i}) \hat{n}_{ij} + kg(r_{ij} - d_{ij}) \hat{n}_{ij} \\ + \kappa g(r_{ij} - d_{ij}) \Delta v_{ij} \hat{t}_{ij} \end{aligned} \quad (2)$$

where $A_i = 2000N$ and $B_i = 0.08m$ [8] are the constants which is considered normal for our desired case, $k = 1.2 \times 10^5 kg/s^2$ and $\kappa = 2.4 \times 10^5 kg\ m^{-1} s^{-1}$. The radius of the sphere is distributed around 0.3 with σ 0.021, where $r_{ij} = r_i + r_j$, r_i and r_j being the radius of the refugees and d_{ij} is the distance between the center of the i_{th} and j_{th} refugee. The unit vector $\hat{n}_{ij}$ which is the unit vector pointing from the sphere i to the sphere j and $\hat{t}_{ij} = (-n_{ij}^y, n_{ij}^x)$ is the tangential directional unit vector. The relative tangential velocity is given by $\Delta v_{ij} = (\vec{v_j} - \vec{v_i}) \cdot \hat{t}_{ij}$. Here, we have used a function $g(x - y) = 0$; if $x \leq y$ or else $g(x - y) = x - y$. A repulsive force is experienced by the i^{th} refugee due to the presence of the walls on the four sides which is given by

$$\begin{aligned} \vec{f}_{iW} = A_i exp(\frac{r_{iW} - d_{iW}}{B_i}) \hat{n}_{iW} + kg(r_{iW} - d_{iW}) \hat{n}_{iW} \\ + \kappa g(r_{iW} - d_{iW}) \Delta v_{iW} \hat{t}_{iW} \end{aligned} \quad (3)$$

where d_{iW} is the perpendicular distance of the pedestrian from the wall and $\hat{n}_{iW}$ is the perpendicular direction from the center of the sphere to the wall.

In our model, refugees are randomly spawned around a food distribution point, outside the food distribution radius (FDR). Initially, we allow the refugees to spawn and then introduce a brief delay before starting the simulation to let the points adjust, preventing them from clustering too closely. This avoids potential issues with the force function at the start, which could lead to unrealistic results like deaths in the spawning step itself.

Once the simulation begins, the refugees move toward the FDR. Upon reaching it, they take a food packet. After collecting the food packet, they leave in either the $\theta = 0°$ or $\theta = 180°$ direction of the FDR. This choice is intentional, as directing individuals to leave from the sides rather than retracing their path minimizes the risk of collisions with the incoming crowd. This strategy aligns with established crowd management practices that emphasize the importance of designated entry and exit routes to maintain order and prevent overcrowding.

In our simulations, we have set the maximum pressure (force per unit circumference of the refugee) a refugee can withstand as $10,800N/m$, beyond which they are considered immobile for the rest of the simulation. While this value is unrealistically high, it was necessary to achieve a qualitatively accurate representation of real-life crowding scenarios. Using more realistic threshold values led to an unrealistically high number of fatalities, which did not align with observed cases of deaths in similar real-world conditions. This adjustment is consistent with prior research on the Social Force Model (SFM) which highlighted concerns regarding the numerical values of forces in the Social Force Model (SFM), noting that while the parameter set provided by Helbing effectively prevents excessive pedestrian overlap, it also leads to artificially high force levels (Lakoba et al., 2005 [14]; Helbing et al., 2000 [8]; Langston et al., 2006 [15]; Lin et al., 2017 [16]). Given these known discrepancies, our approach prioritizes replicating the overall crowd dynamics and emergent behaviors rather than focusing on quantitatively precise force values.

For the obstacle cases , the interaction between obstacles and individuals is the same as the interaction between individuals, but obstacles are considered rigid and immovable circular entities. In our model, we have also implemented corrections to address the non-differentiability of the discontinuous potential as proposed by Koster et al. [13].

RESULTS AND DISCUSSION

In figure 1(a) the screenshot of space at the beginning of the simulation is shown, where refugees represent white spheres. They are all traveling towards the food distribution point, which is placed inside the green circle. When the refugees reach close to the distribution point, the refugees will have to wait to collect the food packet depending on the frequency of distribution of the food packets. The refugees who receive the food, start to retreat in the direction of either $\theta = 0°$ or $\theta = 180°$ from the FDR depending on whichever direction is closer, shown as the blue spheres in Figure 1(b). Those who did not receive the food will continue to move forward towards the food distribution point, till they receive the food packet. The refugees during this process will undergo head-on collisions with fellow refugees and will be seriously injured or die, shown as black spheres in figure 1(c).

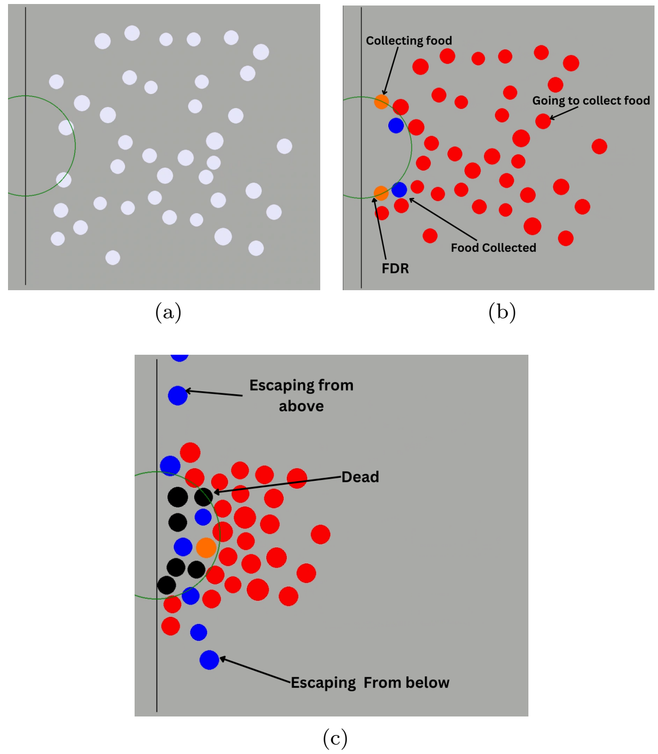

FIG. 1: (a) The snapshot of the system at the start of the simulation, where the white dots are refugees distributed randomly. The green circle is the food distribution radius. (b) The snapshot of the refugees going to collect the food shown as red, the orange sphere are the refugees who are receiving the food at the instant of snapshot and blue sphere are refugees who have received the food and are moving away from the FDR. (c) The snapshot where we observe refugees going to collect the food, refugees receiving the food, refugees going back after collecting the food and some refugees are critically injured/dead due to the pressure exerted by their neighboring refugees.

No Obstacle Case

In a real-life scenario, the volunteers of the refugee camp throw the food packets to a particular distance

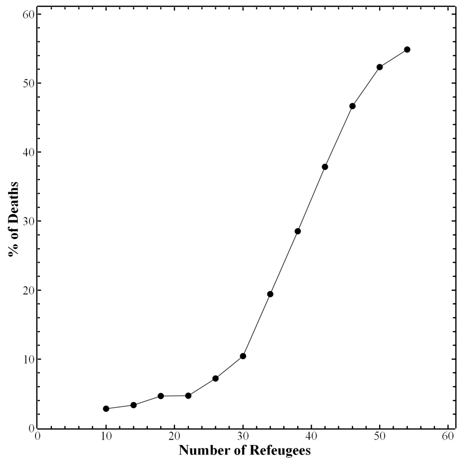

FIG. 2: The percentage of number of people died is plotted against the number of people present in the refugee camp at FDR=2.

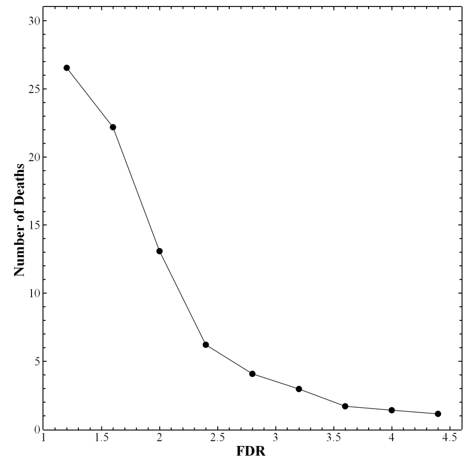

FIG. 3: The number of people died is plotted against the FDR when we consider the total number of people is 40.

when the crowd is driven by panic, for their own safety and better distribution of food packets. The food packet is thrown to a maximum distance called food distribution radius FDR which is assumed to be the length over which the volunteers are throwing the food packets see Supplementary video 1.

Keeping the FDR constant at $2m$, we analyzed the relationship between the total number of refugees and the resulting number of deaths see figure 2. We observed that as the number of refugees increased, the number of deaths also started to rise. Specifically, the percentage of deaths ranged from about 3% when simulating 10 people to about 55% with 54 people. The data revealed a sharp increase in deaths as crowd density grew, which can be seen from figure 2. This sharp increase is due to higher crowd density, which leads to more collisions, restricted movement, and intensified pushing near the food distribution point. As space becomes limited, competition increases, raising the risk of injuries and fatalities.

Then, we simulated the crowd dynamics, keeping the number of refugees constant at 40, and calculated the number of people dying as a function of the FDR. As seen in figure 3, On increasing the radius of distribution, we observed that the number of people dying is reducing. It ranged from around 27 people dying at $FDR = 1.2m$ to just 1 person dying at $FDR = 4.4m$. For FDR above $4.4m$, we do not observe an appreciable change in the number of deaths, and increasing the FDR beyond this is not practically viable. For the rest of the calculation, we have fixed FDR at $2m$ and number of people as 40. The decrease in deaths with a larger FDR is due to the increased available space for food collection, which helps spread the crowd over a wider area, reducing local density. Lower density means fewer collisions and less physical pressure, decreasing the risk of trampling. Additionally, with more space, individuals can collect food more quickly, reducing their time spent in high-density regions and further minimizing the likelihood of dangerous interactions.

A significant cause of death we observed was the collision between incoming refugees and those who have collected food at the FDR. These collisions resulted in deaths, leaving those refugees immobile which further reduced the available area for food collection. This reduction in space also lowered the efficiency of the crowd outflow and food collection, creating more congestion at the FDR, which in turn led to additional collisions and deaths.

One Obstacle Case

To further reduce the number of injured refugees we have to rely on a strategy where the refugees follow a definite pattern of motion with minimal contact without realizing the restriction imposed on their movement. To achieve this we used a simple strategy of introducing an obstacle, a spherical object, which may minimize the interaction between the refugees as shown in Figure 4. The spherical obstacle will act as a passive particle and have a radius r. When the refugees move towards the food distribution point, there will be elastic collisions with other refugees as well as with the obstacle. In the presence of an obstacle, the refugees are forced to escape from either the left or right of the obstacle, reducing their interaction with other refugees who are yet to receive the food. This works similarly to pulling two objects through a narrow opening at the same time, they can get stuck because they push against each other. But if we pull them out one at a time or guide them with a divider, they come out more smoothly. Similarly, the obstacle redirects the crowd, easing the pressure and helping people move more

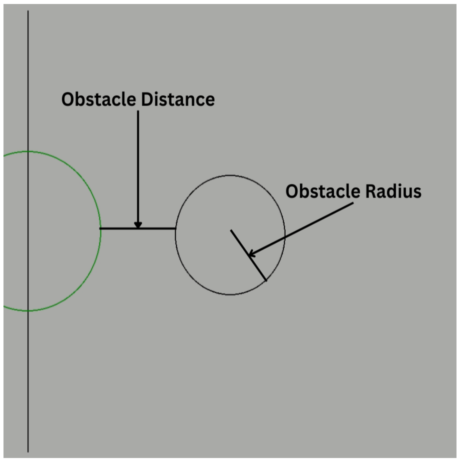

FIG. 4: The model of a single obstacle system where all the parameters are defined for clarity purposes.

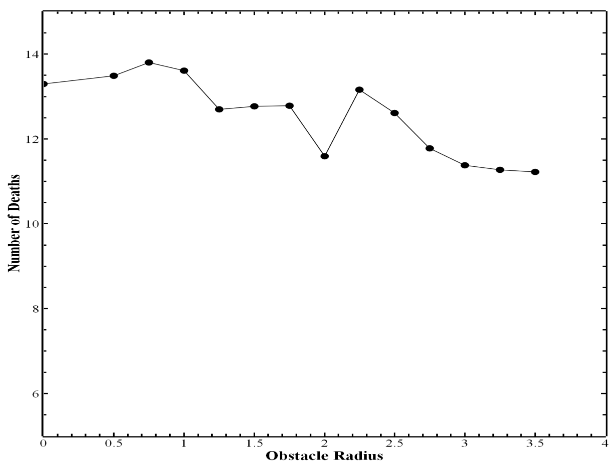

FIG. 5: The recorded number of deaths is plotted as a function of the radius of a single Obstacle system. The obstacle is placed at a constant distance of $0.8m$ from the $FDR = 1m$ throughout the simulation depending on the radius of the obstacle see fig 4.

efficiently, ultimately reducing collisions and preventing fatalities see Supplementary Video 2.

The obstacle has two parameters that can be varied, the radius and its distance from the FDR as shown in Fig.4. The obstacle is placed slightly asymmetrically due to more efficiency as suggested in Helbing [8].

For a total number of 40 refugees, we have plotted the number of dead refugees against varying radii of the obstacle as indicated in Fig. 5. When the obstacle is not present, the number of dead refugees is 13, corresponding to the 0 radius point. On increasing the obstacle radius from $1.25m$ to $3.5m$, while keeping the distance from the FDR constant at $0.8m$, the number of fatalities tends to decrease. The overall trend shows a slight reduction in the number of deaths. Our strategy can reduce the deaths up to 15% when we set the radius to about 1.5 times the FDR compared to the case when the obstacle is not present.

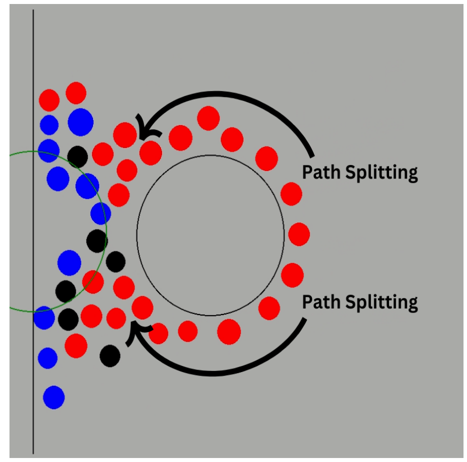

FIG. 6: Snapshot showing the distribution of food packets in the refugee camp, with a circular obstacle placed in front of the FDR. The red disc represents the refugees going to collect the food, the blue disc represents refugees who have already collected the food, and the black sphere represents injured/dead refugees.

This trend can be explained using the idea that the obstacle functions as a natural queue-forming mechanism, increasing the time spread between the first and last refugee reaching the FDR. Since individuals must navigate around the obstacle, it effectively creates two virtual queues (see Fig. 6), slowing their approach. This reduces the effective velocity of movement, leading to a more staggered arrival pattern, i.e., the refugees arrive at the FDR over a longer period rather than all at once. As a result, the crowd density near the FDR decreases, minimizing collisions and lowering the number of fatalities. In the case where the radius of the obstacle is too small, the obstacle acts like a passive refugee and does not shield the outgoing refugees from the incoming refugees. This is observed for the case of obstacle radii less than 1 m, where the number of injured pedestrians is 13, same as that of the case when an obstacle is not present.

When varying the distance of the obstacle from the FDR while keeping the obstacle radius constant at $2m$, we observed distinct trends in the number of deaths as shown in Fig. 7. Between an obstacle distance of $0.8m$ and $1.8m$, the number of deaths decreases, reaching a minimum of approximately 10 deaths, about a 15% reduction compared to the scenario with no obstacle. This reduction occurs because the obstacle promotes an orderly movement among the refugees. Incoming refugees tend to align closer to the FDR, creating a queuing system where they form a single-file queue close to the circumference of the obstacle. Meanwhile, those who have collected food move away from the FDR along the $\theta = 0°$ or $\theta = 180°$ direction. This structured flow significantly

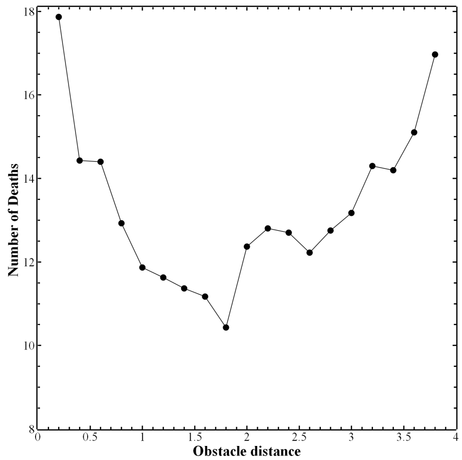

FIG. 7: The number of people died is plotted against the distance of the single Obstacle from the FDR. The radius of the obstacle is kept constant at $2m$

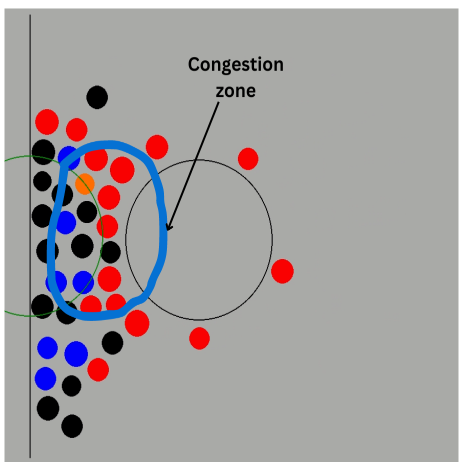

FIG. 8: The snapshot of the simulation shows the increasing number of dead refugees when the obstacle is too close to the FDR.

reduces collisions.

However, when the obstacle distance exceeds $1.8m$, the number of deaths starts to rise again. At this point, the obstacle becomes too far from the FDR, similar to having no obstacle at all. Conversely, when the obstacle is placed too close to the FDR, at distances less than $0.8m$, the number of injuries increases beyond that observed with no obstacle. This proximity limits the space available for refugees to collect food and leave without colliding with others as can be seen in Fig. 8 marked as *Congestion zone*.

This behavior can be analogized to the flow of water. If water flows towards a destination and an obstacle is placed too close, it creates excessive turbulence and strong collisions with the destination. When the obstacle is placed slightly further within an optimal range, it splits the water stream, reducing turbulence and collisions as

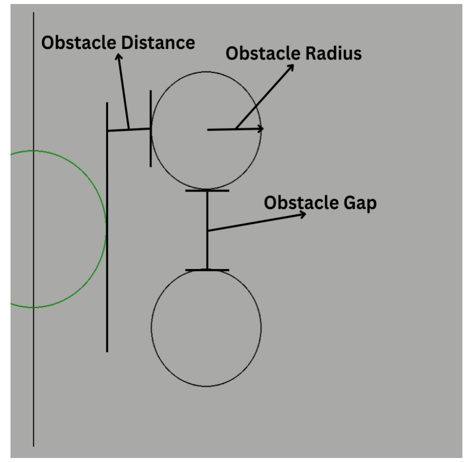

FIG. 9: The model of a two-obstacle system where all the parameters are defined for clarity purposes.

the water reaches its target more smoothly. However, if the obstacle is placed too far away, the split streams remerge before reaching the destination, nullifying the obstacle's effect.

Another thing to note is that beyond an obstacle distance of $3m$, we observed that the number of deaths began to increase, eventually exceeding the count in the no-obstacle scenario. This outcome occurs because the obstacle occupies space where refugees would have otherwise spawned. As a result, the refugees now spawn closer to the FDR, causing them to reach it more quickly. This reduces the spread in time between the first refugee reaching the FDR and the last refugee leaving it, leading to a shorter time window for the entire population to pass through the FDR. The increased density of refugees in this compressed timeframe results in more collisions and, consequently, more deaths. In contrast, without the obstacle, refugees would have spawned further away, taking more time to reach the FDR, which would have reduced crowding and the likelihood of fatal clogging near the FDR.

Two Obstacle Case

To further explore the effect of obstacles on crowd dynamics, we tested a configuration with two obstacles near the FDR. This approach was inspired by previous work, such as the study by Jiang et al.[10], where two obstacles were found to improve crowd outflow. In our simulation, we placed two circular, immovable structures near the FDR and systematically varied different parameters to analyze their impact on the number of deaths.

Across all scenarios with two obstacles, we observed a reduction in the number of deaths compared to both the no-obstacle and single-obstacle configurations. Three key parameters were adjusted and studied in this con-

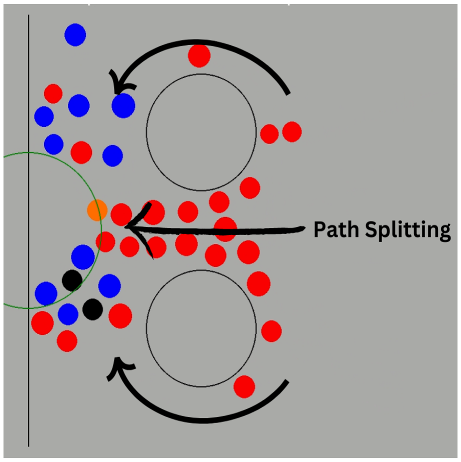

FIG. 10: The snapshot of the two obstacle model shows the refugee's path are split automatically and thus the number of deaths have gone down.

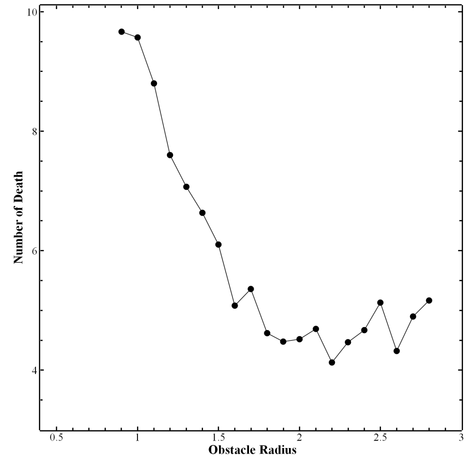

FIG. 11: Number of People died Vs Radius for Two Obstacle case. const Gap=2, Dist=1.2

text: the obstacle radius, the obstacle distance from the FDR, and the gap between the two obstacles as shown in Fig 9. The first two parameters are similar to those in the single-obstacle case, while the third—the gap between the obstacles—provides an additional factor influencing crowd dynamics. To explain why this may work, we will use the water analogy again. In a stream of water flowing towards a destination, when two obstacles are introduced, they split the stream into three distinct sub-streams. These sub-streams flow with less interaction between them, resulting in reduced turbulence in the middle section. The central part, which typically experiences the most pressure and chaotic flow, now sees decreased turbulence due to the splitting. As a result, the overall movement becomes more orderly, reducing the number of collisions and improving the efficiency of crowd outflow, see Supplementary Video 3. Like the single obstacle case, in the two-obstacle system, a similar queueing mechanism is observed, but with a key difference—three paths are formed instead of two. These paths act as areas where people "queue up," with two paths on the outer sides of the obstacles and one in the middle between them see Fig. 10. While the outer paths contribute to spreading out the arrival times at the FDR, the middle path does not significantly increase the staggering effect, as it leads to a more direct approach to the FDR. This setup reduces congestion and fatalities compared to a single obstacle, but the middle path somewhat limits the extent to which the arrival times are staggered compared to a purely single-file system. This may help illustrate why placing two obstacles leads to better outcomes in our simulation compared to a single obstacle or none.

By varying the obstacle radius while maintaining a constant obstacle gap of $2m$ and an obstacle distance of $1.2m$, we observed a consistent decrease in the number of refugee deaths, reaching a minimum of approximately 4 deaths at a radius of $2.2m$ as shown in Fig 11. This represents about a 70% improvement compared to the no-obstacle scenario, which significantly surpasses the 15% improvement observed with a single obstacle. Beyond this optimal radius, further increases did not yield any notable reduction in deaths.

On further increasing the radius, the death count will start to increase. This happens because as the obstacle size increases, refugees tend to take the path around the obstacle that is closest to them, which leads more people to crowd into the middle path. Rather than using the side paths, refugees from both sides of the obstacles converge in the middle region, causing severe congestion see Fig. 10. This increased crowd density leads to higher collisions and fatalities, counteracting the benefits of obstacle placement.

Now, coming to our study of obstacle distance variation, the obstacle radius was kept constant at $1.5m$, and the gap between the two obstacles was fixed at $2m$. The obstacle distances can also be negative, meaning that some part of the obstacle can be slightly behind the FDR see Fig. 9. However, the obstacles were never allowed to overlap with the FDR, consistent with the optimal setup identified in Jiang et al.[10]. In this scenario, we observed that the number of deaths decreased as the obstacle distance increased, reaching a minimum of approximately 4 deaths when the obstacle distance was 0 as shown in Fig. 12. Beyond this point, the number of deaths started to rise again. This configuration led to a significant reduction in deaths, up to 70% compared to the no-obstacle case. This trend was similar to the single obstacle case.

The gap between the two obstacles was varied while keeping the obstacle radius constant at $1.5m$ and the obstacle distance at $1.2m$. The result has been shown in Fig.13. Initially, as the gap increased, the number of deaths decreased, reaching a minimum of about 4 deaths at a gap of $3.4m$. This reduction occurred because the

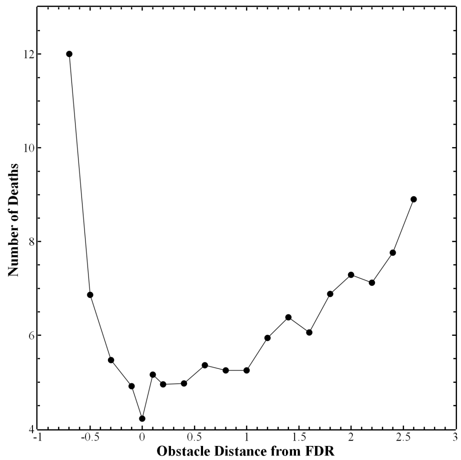

FIG. 12: Number of People died Vs distance of Two Obstacle from FDR. const Gap=2, Rad=1.5

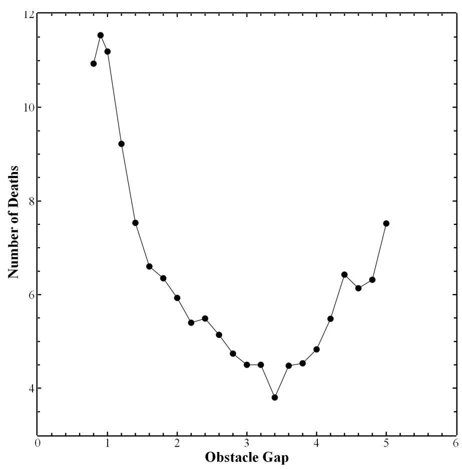

FIG. 13: Number of People died Vs Gap of Two Obstacle. const Dist=1.2, Rad=1.5

initial narrow space between the obstacles was too congested, causing collisions among refugees and with the obstacle walls. As the gap widened, the flow improved, reducing the number of deaths. However, beyond this optimal gap, the number of deaths began to increase again as the setup started to resemble the no-obstacle scenario, diminishing the effectiveness of the obstacles.

CONCLUSION

This paper modeled a scenario of refugee camp inspired by Helbing's model [7]. We tried simulating various strategies and our findings highlight the critical role of crowd density and obstacles in determining the number of injuries and fatalities.

Impact of Crowd Density: The results showed a direct correlation between the number of refugees and the percentage of deaths. As the number of refugees increased, the number of casualties rose significantly, highlighting the dangers of high-density situations in panic-driven environments.

Impact of FDR: We examined the potential of increasing the size of the FDR itself to reduce deaths. While increasing the FDR proved beneficial up to a certain point, beyond that, further increases became impractical and economically unfeasible. This suggests that while expanding the FDR can help mitigate risk, it is not a standalone solution and should be complemented with other strategic measures.

Role of Obstacles: While exploring different strategies, we tried introducing obstacles into our simulation. From our simulation results, we have demonstrated that strategically placing obstacles near the food distribution point helped promote more orderly movement by creating a natural division in the crowd, thereby reducing the frequency and severity of collisions. A single obstacle reduced deaths by approximately 15% as compared to the no obstacle case. However, a more substantial improvement was achieved by using two obstacles, which led to a reduction in deaths by up to 70%.

Optimization of Obstacle Placement: The distance of the obstacle from the food distribution point, the size of the obstacle, and the gap between the two obstacles were critical parameters. When the obstacles were too close or too far from the distribution point, or when their size or spacing was incorrect, the benefits were reduced or reversed, leading to higher casualties. Proper adjustment of these parameters effectively reduced congestion and minimized fatalities. This suggests that there is a delicate balance in the placement and size of obstacles, which must be carefully considered in real-world applications.

Based on our findings, the recommended strategy is to implement two static obstacles on either side of the food distribution point, as this configuration has proven to be the most effective in reducing casualties. If implementing two obstacles is not feasible, a single obstacle can still provide a significant reduction. To maximize the effectiveness of either approach, it is crucial to choose the appropriate combination of obstacle parameters and food distribution radius size. By carefully selecting these settings, the number of casualties can be minimized, making this strategy both practical and life-saving in real-world scenarios.

Another strategy not explored in depth here but worth exploring is increasing the number of food distribution points. This could reduce the number of refugees at each location and potentially lower the number of injuries. However, this may not be the most practical approach, as refugee camps often face logistical constraints, including limited personnel and food supplies.

This study presents a simple yet effective model for understanding panic-driven motion in a refugee camp during a food distribution scenario. The results emphasize the importance of managing crowd density and strategically using obstacles to reduce the number of injuries and fatalities. The model's insights can be applied to improve safety protocols in refugee camps and other similar situations where large groups of people are at risk of panic-driven motion. Future work could explore the impact of different obstacle shapes and multiple distribution points to further enhance the safety and efficiency of such operations.

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SUPPLEMENTARY INFORMATION

Video 1 No obstacle case simulation:- At the beginning of the video, the white spheres represent the refugees in the spawning process before the simulation starts. After 40 of them have spawned appropriately, the simulation starts and the refugees become red spheres. They all start traveling towards the food distribution point, which is the green semi-circular boundary of radius $2m$. When the refugees reach close to the distribution point, the refugees will have to wait to collect the food packet. The refugees who receive the food, start to retreat in the direction of either $\theta = 0°$ or $\theta = 180°$ from the FDR depending on whichever direction is closer. Those who did not receive the food will continue moving toward the food distribution point until they receive the food packet. The refugees undergoing head-on collisions with fellow refugees will be seriously injured or die. In this case, 12 refugees died.

Video 2 Single obstacle case:- Here we have introduced a circular obstacle of radius $2.5m$ represented by the black circle. The number of refugees is 40 and the FDR is $2m$. In this case, we observe that in the presence of the obstacle, the refugees are forced to escape from either the left or right of the obstacle, reducing their interaction with other refugees. So the overall number of deaths has been reduced to 10.

Video 3 Double obstacle case:- Here we have introduced 2 obstacles of radius $1.5m$ represented by the black circles on either side of the FDR with a gap of $3.4m$ between them. The number of refugees is 40 and the FDR is $2m$. In this case, we observe that the stream of refugees gets split into 3 parts, reducing their interaction with other refugees. So the overall number of deaths in this case is 4.