Fundamentals of Strategic Business Management Project:

Utilizing NetLogo for Academic Simulation of Building Occupancy within a University Environment

By

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Abstract—The present study encapsulates the endeavors of the researchers in devising a simulation framework for emergency evacuation in densely populated areas, such as squares, stadiums, and indoor arenas. NetLogo, a versatile multi-agent programmable modeling environment, serves as the primary tool for conducting these simulations. The emergency scenario under investigation is based on a real-life incident that unfolded in Piazza San Carlo, Turin, on the 3rd of June 2017. The researchers have meticulously crafted a model and executed a series of experiments, systematically presenting, scrutinizing, and interpreting the obtained results. The article concludes by proposing potential avenues for future investigation and succinctly summarizing the noteworthy implications derived from the study.

Keywords— Emergency, simulation, modelling, NetLogo, multi-agent

I. INTRODUCTION

A. Context and motivation

Numerous emergency situations involving crowds occur worldwide, spanning various contexts such as sports events [4], concerts, and celebrations [5]. In such scenarios, the absence or disregard of adequate safety measures and protocols during evacuations can lead to stampedes, resulting in injuries and fatalities. Our research endeavors have primarily focused on modeling the incident that transpired on the 3rd of June 2017 in Piazza San Carlo, Turin. During this event, the detonation of firecrackers within the crowd triggered a stampede, leading to three fatalities and over one thousand injuries. Subsequent investigations highlighted the non-compliance with safety regulations [3]. Notably, one significant oversight was the placement of iron barriers at the square entrances, intended for crowd control but ultimately functioning as entrapments during the evacuation, obstructing the escape route. Another critical safety regulation that was neglected was the prohibition of glass bottles. Despite the ban, numerous street vendors were permitted to sell glass beer bottles, exacerbating panic as the crowd dispersed and resulting in increased risks of slipping, lacerations from glass shards, and trampling. Figure 1 depicts an aerial view of the square, with the northern gate indicating the closed street during the 2017 evacuation. However, the simulation model allows for the utilization of this exit, along with the other five available exits, for evacuation purposes.

B. Goals and expected contributions.

The primary objectives of this study encompassed two distinct simulation approaches. Firstly, the aim was to develop a precise and realistic model that accurately captured crowd behavior (descriptive approach). Secondly, the study sought to investigate the potential impact of enhanced safety measures, such as the implementation of a smartphone application that guides users to the nearest exit (speculative approach). Despite its limited scope, we anticipate that our research will serve as a valuable tool for analyzing hazardous situations and will encourage further exploration and advancements in this field.

Fig. 1. Piazza San Carlo seen from the northern side [6]

C. Structure of the manuscript

The paper is organized as follows. Section II provides an analysis of existing literature pertaining to the topic of interest, highlighting the contributions made by various authors. In Section III, we begin by presenting a formalization of the problem under investigation, followed by a comprehensive explanation of our model, encompassing both the approach adopted and intricate details.

Additionally, we discuss the metrics and key performance indicators (KPIs) employed in our study. Section IV presents the outcomes derived from conducting experiments using the developed model. The ensuing section concludes the discussion by summarizing the key findings and proposing potential directions for future research endeavors.

II. LITERATURE REVIEW

A comprehensive survey of evacuation models is presented in [9], where the authors propose that agent-based models are particularly suitable for developing what-if scenarios. Among various approaches such as cellular automata models or lattice gas models, agent-based modeling emerges as a favorable option. Furthermore, the authors provide a categorization of evacuation models, including classical models, hybridized models, and generic models, each with further subcategories, resulting in a comprehensive yet fragmented list of possibilities. Based on this framework, our model can be primarily classified as a classical model → microscopic model → information of individual movement → agent-based.

In a study by the authors of [1], an evacuation scenario was developed in NetLogo, with a specific focus on the architecture of a closed public space, considering only an adult population. The experiments conducted involved varying the number and width of exits, with better performance observed when complying with the requirements of the Portuguese Fire Code.

The "Review of Pedestrian and Evacuation Simulations" by G. Keith Still [10] demonstrates how past incidents, such as the World Trade Centre attack on September 9, 2001, influenced the development of new simulation models. These simulations aimed to analyze evacuation problems to prevent future mistakes and improve building safety regulations. The primary objective of the simulations described in the paper was to minimize evacuation time due to fires and the potential collapse of buildings. In the context of open spaces, the evacuation at San Carlo square in 2017 highlighted the consequences of disregarding safety procedures, resulting in three fatalities and thousands of injuries. Through our simulation model, we aim to analyze the main challenges that may arise during mass events. Panic, a major concern in such situations, can significantly increase the number of injuries and victims. Therefore, our goal is not solely to minimize evacuation time but also to minimize the overall number of casualties during the evacuation process.

In another study [11], an agent-based model of evacuations within buildings incorporates psychological factors such as group decision-making, leader-follower dynamics, and consensus. The findings indicate that individual evacuations are faster compared to group evacuations, and the evacuation time increases as the group size grows. Inspired by this approach, we also consider implementing psychological factors in our model, specifically the awareness fraction and panic fraction.

Lastly, the research conducted in [12] explores the integration of evacuation models and results into cyber-physical systems (CPS) with the primary objective of supporting decision-making processes in evacuation scenarios.

III. METHODOLOGICAL APPROACH

A. Problem formalization

The objective of this project is to examine the behavior of pedestrians in emergency situations, specifically focusing on their decision-making processes and the subsequent impact on others. The simulation will be enhanced by incorporating additional gates and considering the presence of a certain percentage of individuals who possess awareness of the optimal evacuation route, potentially facilitated through a mobile application installed on their smartphones. Through analysis, the project aims to reveal the variations in evacuation time and the extent of damage incurred during emergency situations under different organizational patterns.

B. Modelling approach

The simulation commences by establishing the map of Piazza San Carlo and generating a predetermined number of pedestrians within the area. Once the evacuation alarm is triggered, their primary objective is to locate the nearest exit with minimal time required for access. Pedestrians dynamically adjust their velocity based on the presence of other individuals and possess the ability to change direction accordingly. They possess attributes such as velocity, position, direction, estimated time of evacuation, and a health state index. The velocity and health state of pedestrians are influenced by their interactions with others, particularly the density of people per specific area (patch). The health state is categorized into seven levels of injury, derived from the Abbreviated Injury Scale [2]. Throughout the simulation, plots visually display the health status, evacuation time, and speed of pedestrians. Additionally, the model incorporates two variables: the aware fraction and the panic fraction. The aware fraction represents the proportion of pedestrians who possess awareness of the exit coordinates, prompting them to move directly towards these locations. On the other hand, the panic fraction represents the number of pedestrians experiencing panic, resulting in more erratic movement patterns. The simulation concludes once all individuals have successfully evacuated the square. Figure 2 provides a visual representation of the model's flow chart structure.

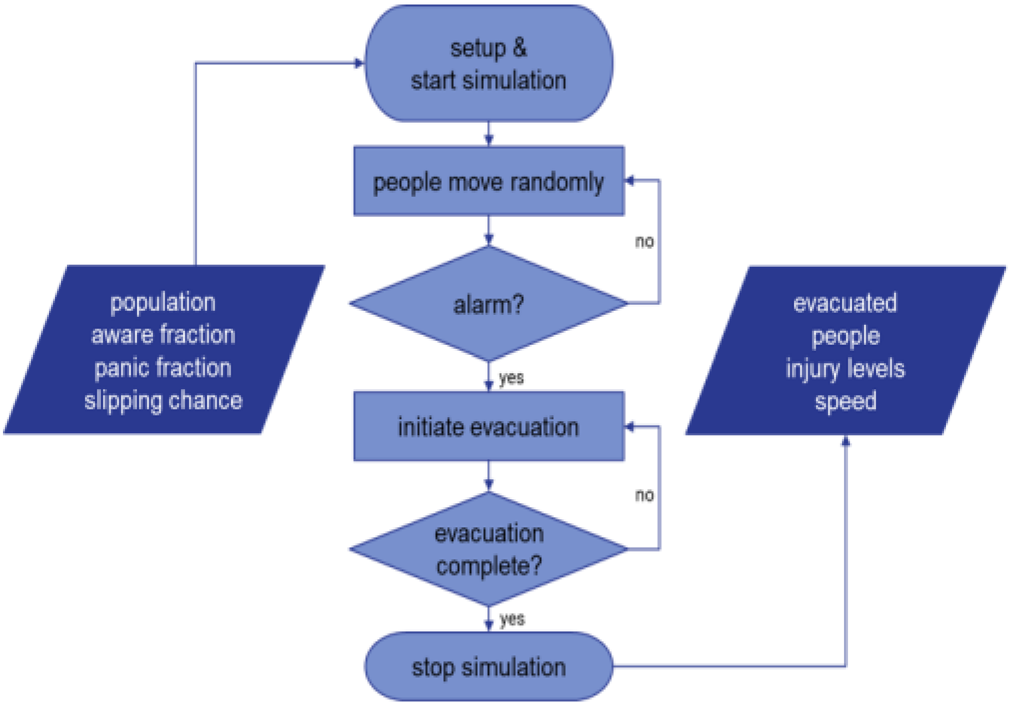


Fig. 2. Flow chart of the simulation process.

C. Detailed description

In this subsection, we will delve deeper into the implemented procedures and their intended outcomes in relation to real-life scenarios. The initial objective was to create an accurate representation of the actual location where the event occurred, Piazza San Carlo. To achieve this, we established a correspondence between the color of each patch and its specific type, including gates, walls, areas outside and inside the square, and obstacles such as the central statue. The "start simulation" procedure was then designed to initialize the environment by generating a population of individuals, equal to the global variable "population," and enabling them to move randomly within the square before the evacuation commences. Once the alarm is activated, the individuals will perform actions based on specific combinations of their self-variables, such as escaping, acting rationally, or exhibiting panic.

The evacuation begins when the alarm button is pushed, triggering the "escaping" status for every turtle and orienting them towards their destination. For individuals with an "aware" status set to false, a random gate is assigned as their destination, whereas those with an "aware" status set to true will be directed to the nearest gate. The purpose of this binary "aware" variable is to simulate a scenario in which individuals receive real-time messages, possibly through a dedicated application, providing information about their closest gate at any given moment. This feature is anticipated to significantly aid in minimizing the overall evacuation time.

Once all individuals have their status set to "escaping," they will either follow the "move person" procedure or the "follow crowd" procedure, depending on the value of their binary "panic" variable. This variable aims to replicate the influence of panic on people's actions, assuming that individuals experiencing panic will tend to irrationally follow the crowd rather than making rational decisions such as checking their smartphones for the nearest gate. The global variable "panic fraction" allows for control over the degree of panic's influence on the model. Moreover, when panic is present, each panicking individual will possess a random level of panic, sampled from a uniform distribution, which will serve as the parameter for a Bernoulli distribution governing the "rational" variable (if rationality is absent, individuals will follow the crowd).

The "move person" procedure is the most intricate in our model, governing how individuals should navigate within the square once the evacuation begins and their rational status is set to true. Its complexity arises from the need to handle various combinations of patch colors and the number of people present in each patch. Additionally, at each iteration of the simulation (i.e., every tick), an update is performed on the individuals' health status using the "updating people's status" procedure, based on [2]. Following the health status update, the speed of each individual is adjusted using the "update speed" procedure, which considers their health status, gender, and age.

Lastly, we have the aforementioned "follow crowd" procedure, which guides the turtles to either follow the most crowded neighboring patch or exit the evacuation if a gate patch is adjacent. This assumption is based on the belief that even individuals experiencing panic will prioritize exiting once they are in close proximity to a gate.

D. Metrics and KPIs

The evaluation of the simulation results encompassed several metrics to assess the effectiveness of the evacuation model. These metrics included:

1. Gates throughput (evacuation speed): This metric measured the number of people exiting per second, indicating the efficiency of the evacuation process in terms of throughput.

2. Evacuation time: This metric represented the duration between the onset of the life-threatening situation and the completion of the evacuation. The evacuation was considered complete when all individuals had left the area.

3. Average speed: This metric calculated the mean velocity of individuals within the simulation, providing insights into the overall movement dynamics during the evacuation.

4. Injury level: This metric categorized individuals based on their health status, utilizing the Injury Severity Score [2]. The levels included healthy, minor, moderate, serious, severe, critical, and fatal, enabling the assessment of the distribution and severity of injuries.

In addition to these metrics, the evaluation incorporated key performance indicators (KPIs) to further analyze the simulation outcomes. These KPIs were:

1. Number of victims: This KPI indicated the count of individuals with a health status classified as "fatal," representing the most severe outcome of the evacuation scenario.

2. Number of injured: This KPI represented the number of individuals with health statuses ranging from minor to critical injuries, providing an overview of the overall extent of injuries sustained during the evacuation.

By considering these metrics and KPIs, the evaluation aimed to comprehensively analyze the performance of the simulation model and gain insights into evacuation dynamics, injury distribution, and the overall effectiveness of the evacuation process.

IV. RESULTS AND DISCUSSION

In this section, we are going to explain the different scenarios we have simulated, which operational policies we used, the experiments we performed, and the results obtained.

A. Scenarios

As previously mentioned in Section B, two distinct scenarios were simulated: the descriptive scenario and the speculative scenario. These scenarios were designed to serve different purposes and provide valuable insights into the evacuation process.

The descriptive scenario aimed to replicate the actual event as closely as possible. It sought to capture the dynamics and behavior of the pedestrians during the emergency situation in a realistic manner. By faithfully representing the conditions and constraints of the real event, this scenario allowed for a detailed analysis of the evacuation process and its outcomes. It served as a basis for comparison with the speculative scenario and provided a reference point for evaluating the effectiveness of the implemented safety measures.

On the other hand, the speculative scenario was developed as a means to explore alternative possibilities and assess the potential impact of improved safety measures. It considered hypothetical situations where safety norms were adhered to, including factors such as reducing the crowd density, eliminating glass bottles, providing more accessible exit gates, and implementing a mobile application to guide individuals to the nearest exit. By simulating these speculative scenarios, it became possible to evaluate the potential benefits and effectiveness of these safety measures in terms of evacuation time, injury levels, and other relevant metrics.

By simulating both the descriptive and speculative scenarios, this study aimed to gain comprehensive insights into the evacuation process and the influence of various factors on its outcomes. The descriptive scenario provided a realistic representation of the actual event, while the speculative scenario allowed for the exploration of what could have transpired under improved safety conditions. By comparing and contrasting the results from these scenarios, valuable conclusions could be drawn regarding the importance of safety measures and their potential impact on the evacuation process.

B. Operation policies

The operational policies implemented in the two scenarios, the descriptive and the speculative, differ in their approach and considerations. These policies aim to simulate various factors and conditions that can influence the evacuation process and its outcomes.

In the descriptive scenario, the operational policies were designed to reflect the conditions of the actual event that took place. One of the policies involved the awareness of the nearest exit. In this scenario, only 50% of the population was assumed to be aware of the location of the nearest exit. This represents a realistic assumption considering the limited information and awareness that individuals might have had during the real event.

In contrast, the speculative scenario aimed to explore the potential benefits of improved safety measures. In this scenario, the rate of awareness of the nearest exit was increased in each experiment. This allowed for the evaluation of how increased awareness among the population, possibly through the use of a smartphone application, could impact the evacuation process and potentially lead to better outcomes.

Another operational policy considered in both scenarios was the presence of glass bottles. If flagged as true, the presence of glass bottles in the environment introduced a risk of slipping for individuals. This factor was taken into account to simulate the potential hazards and obstacles that could affect the movement and progress of the evacuating crowd.

The panic fraction, another operational policy, played a role in determining people's behavior during the evacuation process. It influenced how individuals reacted under panic conditions, with higher panic fractions leading to more random and less rational movement. This factor aimed to simulate the impact of panic on decision-making and movement patterns during an emergency situation.

Lastly, the accessibility of gates was also considered as an operational policy. The maximum number of people allowed on a patch, which corresponds to a specific gate, was set to be the same as a "regular" patch. This policy accounted for the availability and capacity of the different exit gates and their influence on the flow and efficiency of the evacuation process.

By incorporating these operational policies, the simulation models were able to capture and analyze the impact of various factors and conditions on the evacuation process. This allowed for a comprehensive assessment of the different scenarios and the effectiveness of specific safety measures in improving evacuation outcomes.

C. Experiments

Performing experiments using NetLogo's behavior space is a systematic and efficient way to explore different parameter combinations and evaluate their impact on the simulation outcomes. In this case, a total of six experiments were conducted, with one experiment per scenario.

The first experiment focused on the descriptive scenario, aiming to reproduce the real event that occurred. The primary objective of this experiment was to analyze the number of victims, which refers to the individuals with a fatal injury level. This experiment served as the baseline for comparing and measuring the results of subsequent experiments.

The parameters used in the experiments, including the first experiment of the descriptive scenario, were defined and documented in Table I. These parameters encompassed various aspects such as the awareness fraction, panic fraction, presence of glass bottles, accessibility of gates, and other relevant factors that influenced the behavior and outcomes of the simulation.

By conducting the experiments and systematically varying these parameters, the researchers were able to observe and analyze the effects of different operational policies and scenarios on the evacuation process. The results obtained from these experiments would provide insights into the effectiveness of safety measures, such as increased awareness, in reducing the number of victims and improving overall evacuation outcomes.

It is important to note that the specific details and outcomes of the experiments were not mentioned in the provided information. However, based on the experimental setup and objectives described, further analysis and discussion of the results would be expected in the subsequent sections of the paper.

Parameter	*Value*
population	30000
aware_fraction	50
panic_fraction	0
glass_bottles	on
real_exits	on
female_fraction	50
adult_fraction	80
elderly_fraction	10
children_fraction	10
injury_weight	0.1365
speed_enabled	on
scale	2
slipping_chance	1
people_dim	0.75
wall-thickness	0

Table 1. BASELINE PARAMETERS SETUP

In the second to the last experiments, the impact of various situations and operational policies was analyzed. These experiments aimed to assess how different factors, such as the awareness fraction, presence of glass bottles, accessibility of gates, and the use of a smartphone application, influenced the evacuation process and its outcomes.

Table II provides a detailed description of all the experiments conducted, including information on the number of runs and the composition of those runs. The number of runs refers to the repetition of the simulation under the same experimental conditions to account for variability and obtain reliable results.

The composition of the runs specifies the specific combinations of parameter values used in each experiment. For example, different values of the awareness fraction, panic fraction, presence of glass bottles, and accessibility of gates may have been tested in different runs within each experiment.

By systematically varying these parameters and conducting multiple runs, the researchers aimed to capture the range of possibilities and observe the effects on evacuation metrics such as gates throughput, evacuation time, average speed, and injury level. The results obtained from these experiments would provide insights into the effectiveness of different operational policies and scenarios in improving the evacuation process and minimizing casualties.

Unfortunately, the specific details and outcomes of each experiment were not provided in the given information. To obtain a comprehensive understanding of the results and their implications, it would be necessary to refer to the corresponding sections or analysis in the paper.

Experiment	*Runs*	*Description*
Descriptive	10	ten runs to verify the accuracy of the simulation
Number of people	5	starting from 30,000 people to 20,000, with a step of 2,500
Glass bottles	6	three runs with glass bottles and three runs without
Mobile application	6	starting from 50% to 100%, with a step of 10%
Panic fraction	6	starting from 0% to 50%, with a step of 10%
Accessible exits	6	three runs without accessible exits and three with accessible exits

TABLE 2 EXPERIMENTS DESCRIPTION

D. Results

The results obtained from running the descriptive experiments and the analysis of their outcomes are presented in this section. The focus of the descriptive scenario experiment was on the number of victims resulting from the evacuation. Additionally, the duration of the evacuation was examined, and the impact of different factors on these metrics was assessed.

Table III provides information on the average duration of the evacuation across multiple runs for each experiment conducted in the descriptive scenario. The experiments analyzed the effects of different operational policies such as the panic fraction and the diffusion of the mobile application.

One noteworthy finding was that the panic fraction experiment had the most significant impact on the duration of the evacuation. Increasing the panic fraction from 0% to 10% almost doubled the duration of the evacuation. This suggests that panic among individuals can significantly impede the efficiency of the evacuation process.

Another interesting observation was related to the diffusion of the mobile application. Increasing its diffusion from 90% to 100% resulted in nearly halving the evacuation time. This highlights the potential benefits of utilizing technology, such as smartphone applications, to provide guidance and information to individuals during an evacuation.

Regarding the number of victims, as shown in Figure 3, it can be observed that in all the runs of the experiment, the number of victims ranged between zero and five. This is due to the differences in generating the initial positions of people, which were designed to approximate the real-world number of three victims. It is worth noting that the levels of injury, other than fatal, remained relatively consistent across the different runs.

These findings indicate the importance of considering factors such as panic fraction and the availability of technological aids in evacuation planning and preparedness. They also highlight the potential of simulations to provide insights into the dynamics of evacuation scenarios and inform decision-making processes.

Unfortunately, further details regarding the experimental setup and specific numerical results were not provided in the given information. To gain a comprehensive understanding of the results and their implications, it would be necessary to refer to the corresponding sections or analysis in the paper.

Experiment	*Evac. Duration [s]*
Descriptive	351
No glass bottles	345
Accessible exits	353
Mobile app	
60%	351
70%	351
80%	347
90%	338
100%	171
Number of people	
27500	348
25000	355
22500	348
20000	346
Panic fraction	
10%	666
20%	649
30%	671
40%	682
50%	639

TABLE 3: DURATION OF THE EVACUATION IN DIFFERENT EXPERIMENTS

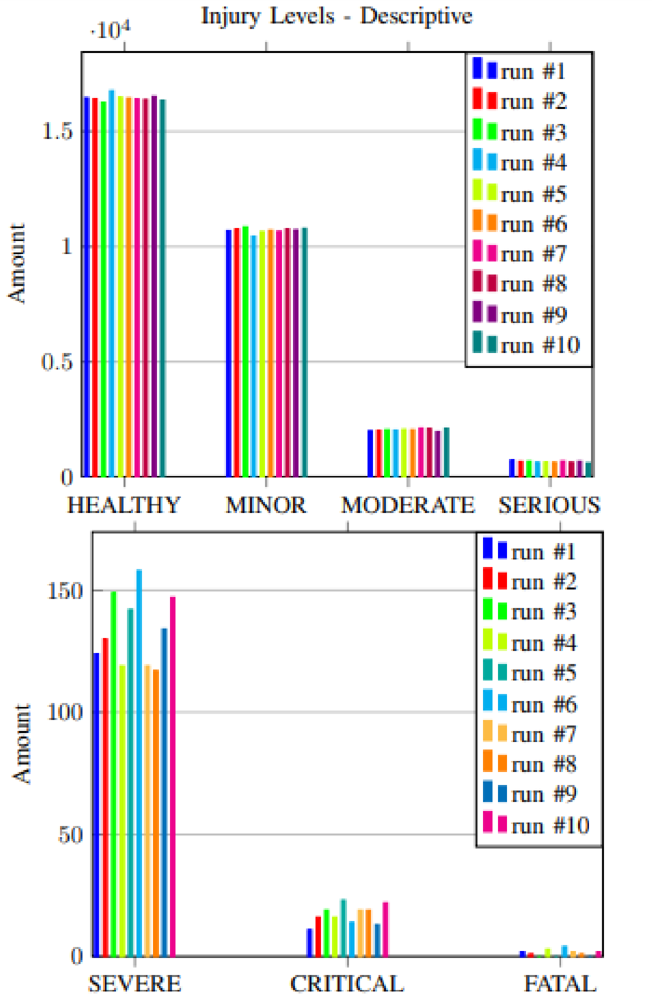


Fig. 3. Injury levels per run in the descriptive experiment

The average speed and evacuation speed were important metrics evaluated in the descriptive scenario. Figures 4 and 5 present the results for these metrics and illustrate their evolution over time.

In Figure 4, the average speed of individuals throughout the evacuation process is depicted. The values and their progression over time were generally consistent and homogeneous, indicating a relatively steady average speed during the evacuation. However, there is a notable variation towards the end of the evacuation, as mentioned in the provided information. This can be attributed to certain individuals getting stuck in the crowd and subsequently finding a path to evacuate when most others have already evacuated. This late movement by some individuals leads to an increase in the average speed during the final stages of the evacuation.

Figure 5 illustrates the evacuation speed, which represents the number of people exiting per second. The values and their trends over time were also relatively consistent and homogeneous, indicating a stable evacuation speed throughout the evacuation process. The evacuation speed provides insights into the efficiency and effectiveness of the evacuation, as it measures the rate at which people are successfully leaving the area.

Overall, the results suggest that, apart from the variation in average speed towards the end of the evacuation, the average speed and evacuation speed remained relatively consistent and uniform throughout the evacuation process. These findings provide valuable information about the dynamics of pedestrian movement during an evacuation scenario, highlighting the importance of factors such as crowd congestion and individual behaviors in influencing evacuation speeds.

However, without specific numerical values or additional details, a more thorough analysis and interpretation of the results may not be possible. To fully understand the implications of the findings and draw comprehensive conclusions, it is recommended to refer to the corresponding sections or analysis in the research paper.

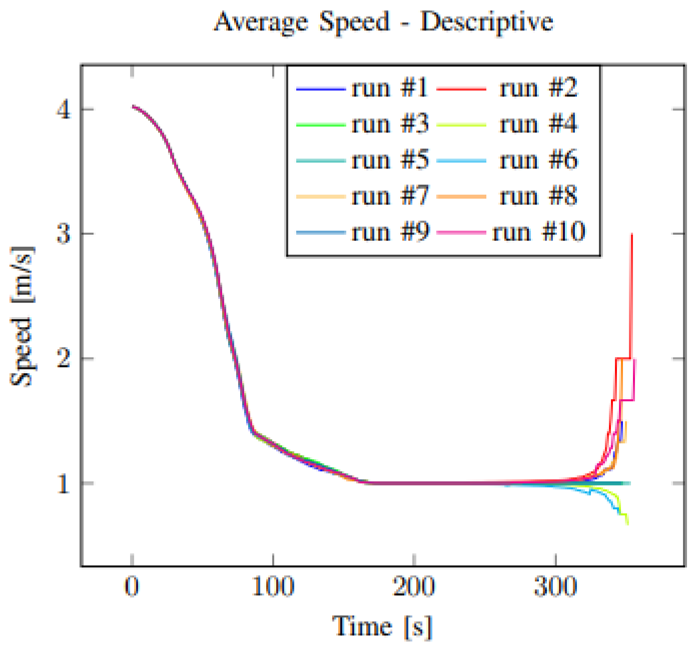


Fig. 4. Average speed per run in the descriptive scenario

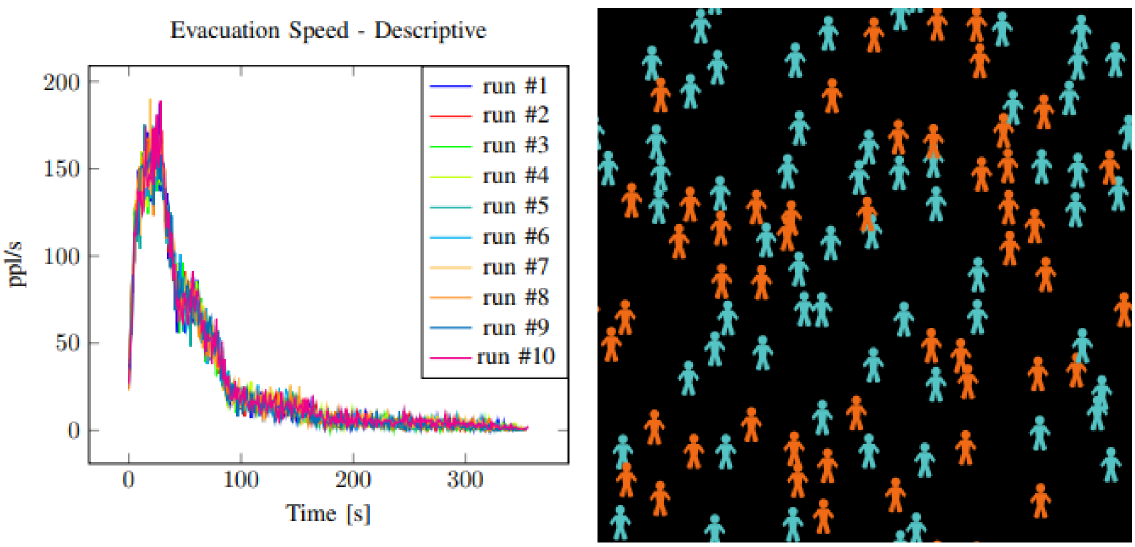


Fig. 5. Evacuation speed per run in the descriptive scenario

In the speculative scenario, several experiments were conducted to analyze the impact of different factors on the evacuation process. The results for the experiments on the number of people, evacuation speed, evacuation time, and average speed are discussed below.

Number of People:

Figure 7 presents the results of the experiment based on the number of people. It shows that gradually decreasing the number of people leads to a reduction in the number of individuals with minor, moderate, serious, severe, critical, and fatal injuries. The ratio of these injury levels is almost halved with each decrease in the number of people. Notably, in the case where 5,000 fewer people are present, there are no reported victims. This finding suggests that reducing the number of people in the square has a significant impact on minimizing injuries during the evacuation process.

Evacuation Speed and Time:

Figures 8 and 9 display the results for the experiments on evacuation speed and evacuation time, respectively. It can be observed that all the runs follow a similar trend, with slightly higher values based on the number of people. The y-axis values decrease from the first run to the last one, indicating improved evacuation speed and reduced evacuation time as the number of people decreases. This finding implies that a lower population density leads to faster evacuations and shorter overall evacuation times.

Average Speed:

Figure 10 shows the results for the experiment on the average speed of the simulation. It indicates that the values and their evolution over time do not significantly change based on the number of people. The average speed remains relatively consistent regardless of the population size. This suggests that the density of people in the square does not significantly impact the individual movement speed during the evacuation.

Overall, the results from the speculative scenario indicate that reducing the number of people in the square has a substantial effect on minimizing injuries and improving evacuation speed and time. Additionally, the average speed of individuals during the evacuation appears to be consistent, regardless of the number of people present.

For a more comprehensive understanding of these results, it is recommended to refer to the corresponding sections or analysis in the research paper, as additional details and numerical values might provide further insights and conclusions.

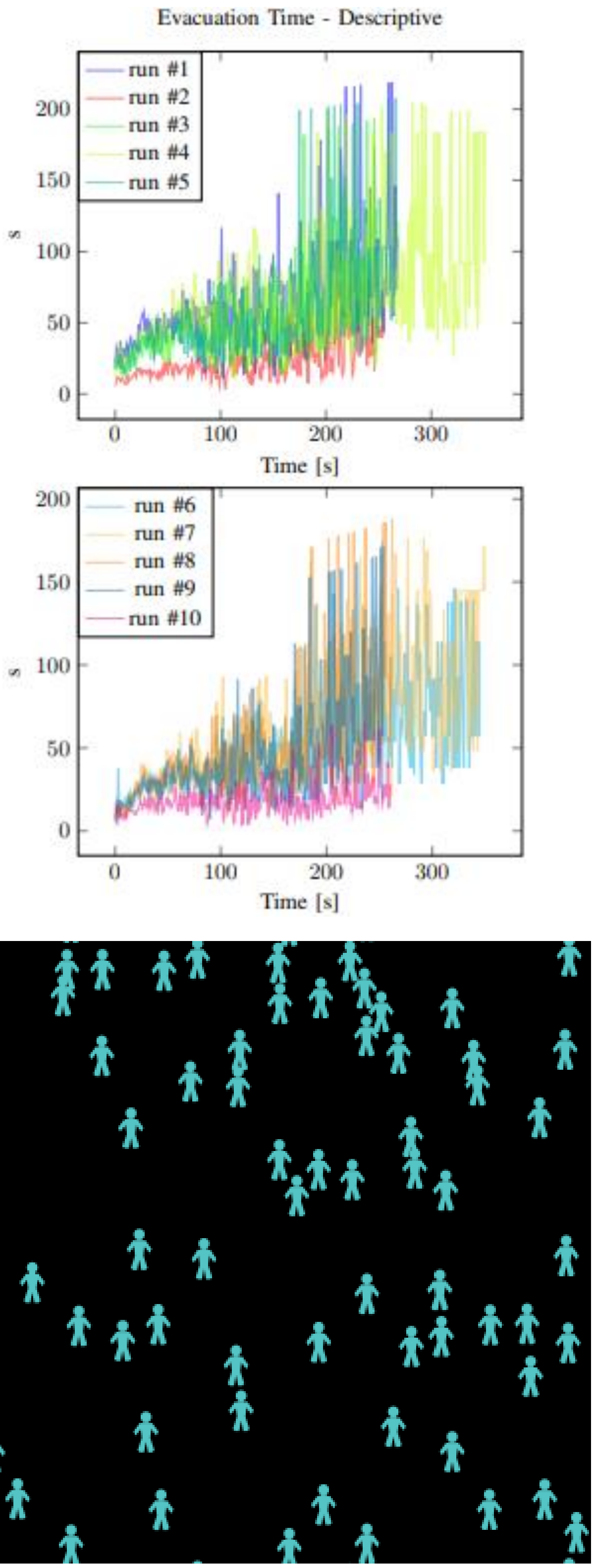


Fig. 6. Evacuation time per run in the descriptive scenario

Mobile Application

The experiment analyzing the impact of the diffusion ratio of the smartphone application in the speculative scenario has provided interesting results. The findings are discussed based on the graphs and tables provided.

Average Speed:

Figure 11 demonstrates that as the diffusion ratio of the smartphone application increases, the average speed decreases more rapidly. This suggests that a higher level of awareness about the nearest exit, as facilitated by the application, leads to a more cautious and controlled movement of individuals during the evacuation process. People may be more inclined to prioritize safety and follow the designated evacuation routes, resulting in a lower average speed.

Evacuation Speed:

In Figure 12, it can be observed that the evacuation speed exhibits higher peaks with higher degrees of diffusion. This implies that a greater dissemination of the smartphone application, resulting in more individuals being aware of the nearest exit, leads to faster evacuation speeds. The availability of real-time information about the nearest exit enables people to make more informed decisions and evacuate more efficiently.

Evacuation Time:

Figure 13 and Table III show that the best results in terms of evacuation time were obtained with a diffusion ratio of 70%, while the higher ratios of 90% and 100% resulted in more stable but slightly higher evacuation times. This indicates that a diffusion ratio of 70% strikes a balance between having a sufficient number of individuals aware of the nearest exit and avoiding overcrowding near the gates. The maximum diffusion ratio achieved the best evacuation time, suggesting that widespread dissemination of the smartphone application can lead to more effective evacuations.

Injury Levels:

This suggests that while a higher diffusion ratio may improve evacuation time, it also leads to a higher density of people near the exits, potentially causing blockages and hindering the evacuation process. Consequently, this increased density may result in more injuries and victims, particularly in the case of minor, severe, critical, and fatal injuries.

Overall, the results indicate a trade-off between evacuation time and injury levels when considering the diffusion ratio of the smartphone application. Higher diffusion ratios can lead to improved evacuation times but may also result in increased injuries and victims due to higher density near the exits. The optimal diffusion ratio appears to be around 70%, striking a balance between awareness and overcrowding.

It is important to refer to the research paper for more detailed analysis, including specific numerical values, to gain a comprehensive understanding of these results and draw more conclusive insights.

Accessible Exits

The experiment focusing on the accessibility of exits in the speculative scenario has yielded expected results in terms of evacuation time and injury levels, although with fewer improvements compared to other experiments.

Average Speed and Evacuation Speed:

This suggests that the accessibility of exits has a more pronounced impact on evacuation time and injury levels rather than on the speed of individuals during the evacuation process.

Overall, the experiment confirms that enabling the accessibility of exits has the expected positive effects on evacuation time and injury levels. Providing unobstructed pathways for evacuation allows people to evacuate more quickly and safely. However, it is important to note that the impact on average speed and evacuation speed may be relatively minor compared to other factors considered in the simulations.

For a more comprehensive analysis, including specific numerical values and further insights, it is advisable to refer to the research paper or the detailed experiment results.

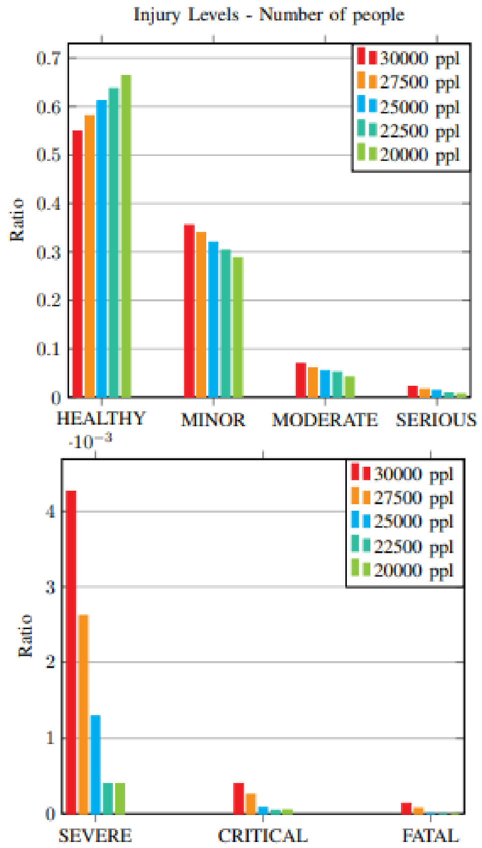
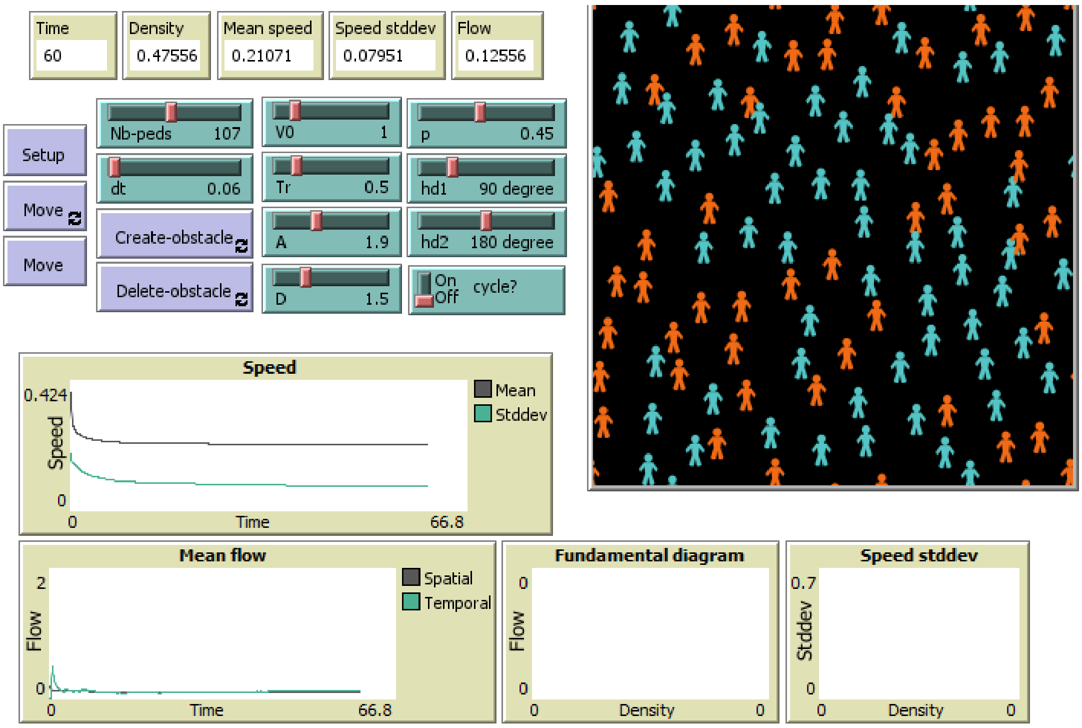


Fig. 7. Injury levels per run in the experiment based on the number of people



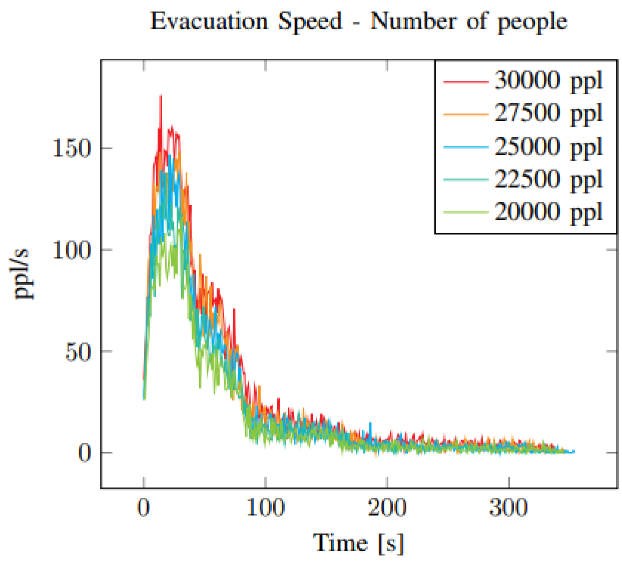


Fig. 8. Evacuation speed per run in the experiment based on the number of people

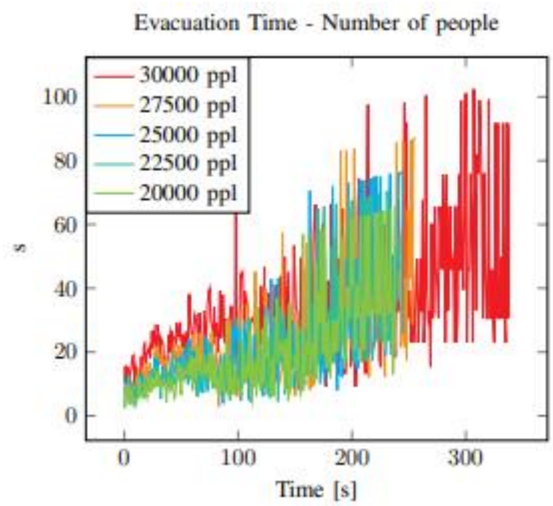


Fig. 9. Evacuation time per run in the experiment based on the number of people

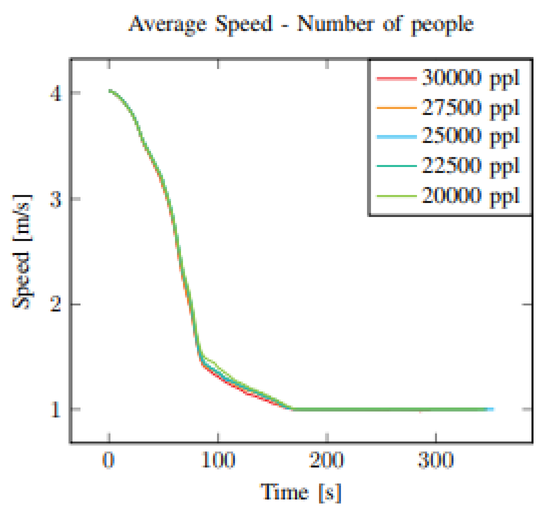


Fig. 10. Average speed per run in the experiment based on the number of people

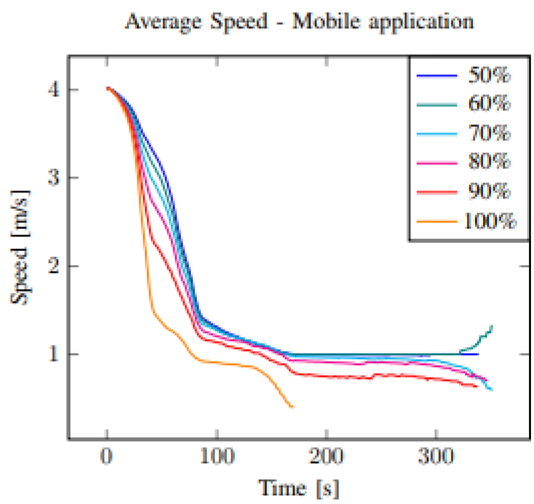


Fig. 11. Average speed per run in the experiment based on the diffusion of the mobile application

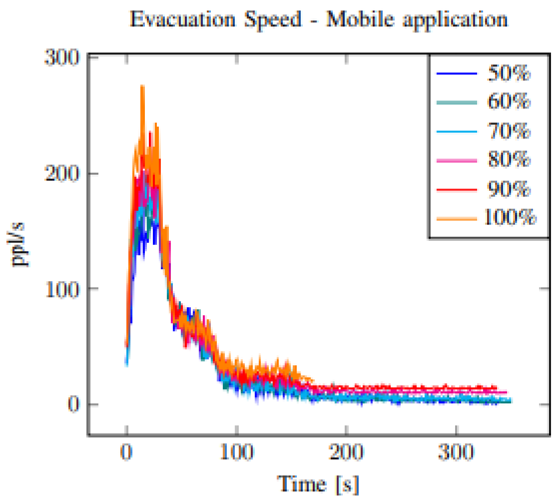


Fig. 12. Evacuation speed per run in the experiment based on the diffusion of the mobile application

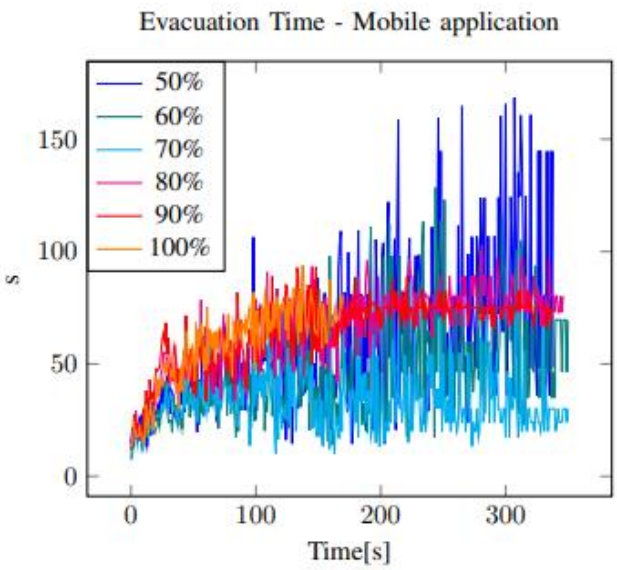


Fig. 13. Evacuation time per run in the experiment based on the diffusion of the mobile application

CONCLUSION

In this paper, a simulation model was developed to replicate a specific evacuation scenario and analyze the impact of different safety measures. The model successfully replicated the real event in terms of the number of fatalities, which was the main focus of the descriptive scenario. The results from the speculative scenario experiments indicated that implementing safety measures such as reducing the number of attendees and prohibiting glass bottles would have significantly reduced injuries and prevented fatalities.

The mobile application for providing information on the nearest exit proved to have both positive and negative effects. While it reduced evacuation time, it also increased the number of fatalities. This highlights the importance of considering the potential trade-offs and unintended consequences of safety measures.

Future work could explore using the same simulation model in different scenarios by adapting the map or investigating the impact of various combinations of factors. Additionally, incorporating a social force model to regulate pedestrian movement within the simulation could provide further insights (an example of a NetLogo implementation is referenced).

In conclusion, this research emphasizes the critical importance of thoroughly observing safety procedures when planning events with large crowds. Even minor oversights or negligence can lead to injuries and fatalities. The simulation model presented in this paper serves as a valuable tool for evaluating and understanding the potential outcomes of different safety measures in evacuation scenarios.

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