Exploring Crowd Management and Evacuation Strategies using Microscopic Pedestrian Simulation: A Case Study of Souq Waqif

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Abstract

Safe egress plans are critical for crowd evacuation at touristic attractions, particularly during special events, as visitors are often unaware of their options. Identification of bottlenecks in the walking spaces are vital for the development of safe and efficient crowd management and evacuation plans. This paper aims to explore crowd management and evacuation strategies for pedestrian egress flow in Souq Waqif, which is a famous touristic attraction in Doha, under varying crowd demand conditions. PTV Viswalk pedestrian simulation tool was used to evaluate crowd evacuation strategies and identify potential bottlenecks during the egress of crowds. Several guided and unguided evacuation scenarios were developed to understand the egress patterns to the allocated assembly areas inside the Souq. The crowd demands and densities were estimated using publicly available data. Eight major locations were identified as the bottleneck during the simulation. Simulation outcomes highlighted that the current evacuation plans and assembly locations are inadequate in providing safe evacuation routes. However, guided scenarios reduced evacuation times considerably when compared to unguided scenarios, particularly when the demand is high. A sensitivity analysis was also conducted to identify the effect of variations in walking behavior parameters in the simulation model. Variations in the walking behavior parameters changed the evacuation times considerably. Thus, proper calibration of walking behavior parameters considering local conditions could improve simulation accuracy. This study helps to identify probable bottlenecks and their characteristics that could help policymakers to assess the effectiveness of evacuation plans and crowd management strategies for crowd safety.

Keywords: Crowd management; Simulation; Pedestrian safety; Crowd evacuation; Historical sites

1 Introduction

Safe crowd egress, particularly during emergencies, is of utmost importance for the reduction of pedestrian injuries and fatalities. The causalities or fatalities might rise if evacuation times increase due to wrong exit selection caused by inadequate guidance or due to pushing and stampedes caused

by panic (Vilar et al., 2018; Zheng et al., 2009). Moreover, tourists are often unaware of safe egress routes and are thus highly vulnerable during emergencies (Sabashi et al., 2022). Proper signage including new innovative methods for wayfinding has been suggested by some researchers as effective means of escape during emergencies (Carattin & Brannigan, 2012). However, the evaluation and selection of suitable solutions and preventive measures for improving safety require consideration of numerous scenarios (Bakar et al., 2017). The number of scenarios to be tested and the cost related to testing such scenarios make crowd simulation tools to be the right decision-support tool that can be used to predict the behavior of the system (Chu et al., 2015). Thus, simulation tools can be used to model crowd evacuations under different conditions, particularly emergencies, to assist decision-makers to make the right solution. Moreover, simulation results can aid in the modification of the built environment to prevent emergencies (Sagun et al., 2011). This is crucial as experimental studies suggest that exiting pedestrians make exit choices based on the characteristics of the queue (speed and length) rather than route length or exit width (Bode et al., 2015).

A major challenge in using pedestrian evacuation simulation tools is the validation of such tools due to the complexity of acquiring data regarding social and psychological factors (Chen et al., 2021). Nevertheless, the Viswalk Crowd simulation tool based on Social Force Model has been found to simulate crowd escape under normal conditions with reasonable accuracy (Martén & Henningsson, 2014; Shi et al., 2021). However, the simulation of emergency conditions showed less frequency of the "faster is slower" effect, obstacle effect, and clogging effect when compared with the empirical data (Shi et al., 2021). Other studies suggest that the social force model and Viswalk simulation tool help illustrate pedestrian interactions, although a combination of more than one approach could provide better results (Jain et al., 2020; Zheng et al., 2009).

The present study focuses on the analysis of various scenarios for crowd evacuation at Souq Waqif which is a heritage site located in the Msheireb district of Doha and comprises an area of 164,000 m^2. Further, as shown in Figure 1, it is located in the vicinity of other famous tourist attractions. It is a labyrinth market founded 100 years ago for the trade of livestock goods (Furlan & Faggion, 2015; Khan et al., 2021). To preserve the architectural and historical identity of the Souq, it was reconstructed and restored in the years 2006 – 2008. It is now a blend of traditional Qatari architecture and modern functional spaces making it one of the top tourist attractions in Qatar. It is also anticipated that the Souq would be a prime destination for tourists visiting Qatar during future mega-events. Safety and efficiency of these crowd flows should be guaranteed, particularly during critical situations, i.e., potential evacuation situations and high-density situations. A simulation of crowd evacuation for a part of Souq Waqif was undertaken by Abdelaal et al (2020), who concluded that for higher crowd densities and emergencies, the route choice remains the same. Moreover, crowd densities as high as 6 p/m^2 were observed at junctions and gates (Abdelaal et al., 2020).

The present paper focuses on various scenarios for simulation designed based on the existing and forecasted demand on the pedestrian corridors of Souq Waqif to analyze the variation in evacuation times. The entire area designated as Souq was used for the simulation under normal conditions. A proposed solution based on providing effective guidance to pedestrians to the exit that will result in lesser evacuation time was simulated. In addition, the sensitivity of the simulated model to various walking behavior parameters was also studied.

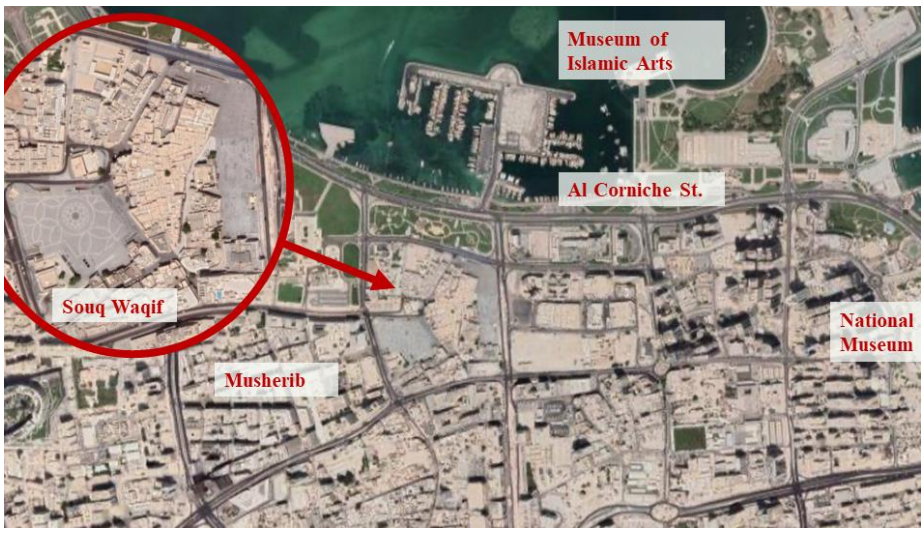

Fig.1: Souq Waqif area considered for the present study

2 Methodology

2.1 Data Collection

In this study, publicly available data, such as newspaper articles, Google Maps, and YouTube videos, were used to acquire the required data. The crowd demands were estimated for an event day scenario based on a press release ("2017 "زوار سوق واقف بالآلاف.. و12 الف زائر يوميا بسوق الوكرة,) that gives the total number of daily Souq visitors during the Eid period. This value was estimated at 60,000 visitors per day. To estimate the number of visitors per hour, data from google maps for different attractions in the Souq that shows the variations in demand was used. Projecting this data to the entire Souq gave the pedestrian demand (Figure 2). The demand reached 19800 pedestrians during the peak hour (9:00 pm -10 pm).

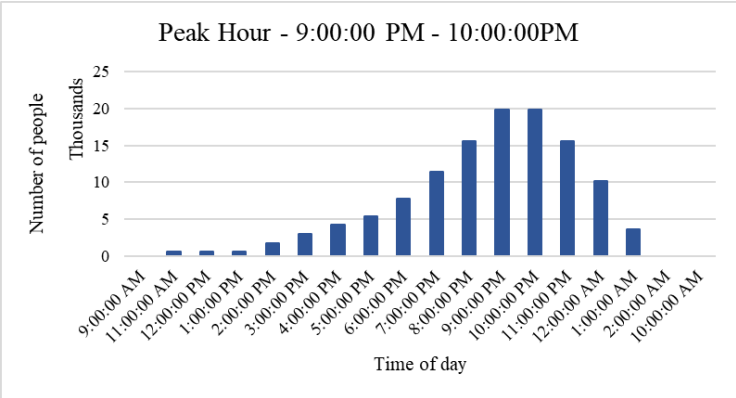

Fig. 2: Estimated pedestrian demand of Souq Waqif during an event

The crowd density was calculated based on video footage from (Rahman.YouTube., 2013) by counting the number of people within a known area. The footage highlights the main street in Souq Waqif as well as the square in front of the police station during the Eid period. The densities were estimated as 1.22 ± 0.07 p/m^2 and 1.59 ± 0.02 p/m^2 for the major walkway and junction in Souq Waqif. These pedestrian densities represented the level of service E – F based on Highway Capacity Manual criteria for walkways. The pedestrian demand for each corridor was determined based on the estimated densities so that the total demand remains at 19800 pedestrians per hour.

2.2 Scenario Design

A range of different scenarios was considered for the simulation as listed in Table 1. As per the Doha Metro Ridership forecast shown in Figure 3, it was predicted that there will be an increase of 50% in ridership by 2022 when compared with 2020 (Kovessy, 2015). Therefore, a similar projection for the number of pedestrians for the Mega Event scenario was assumed for the demand estimation of the number of pedestrians who will visit the Souq during future mega events that will be held in Qatar. An intermediate stage with an increase of 20% of the event day scenario was also considered. The normal day scenario was designed with half the demand of the event scenario.

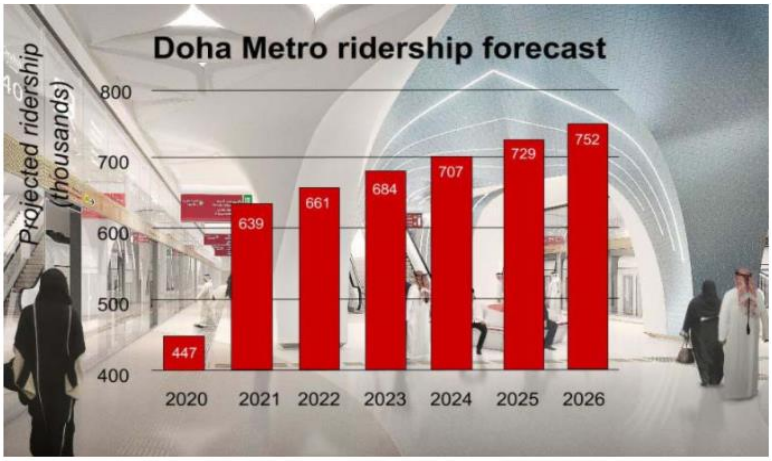

Fig.3: Doha Metro ridership forecast for 2020 to 2026

Table 1: Scenarios for simulation

Scenario	Conditions	Description	Number of Pedestrians in Peak Hour
NORMAL DAY	Guided Unguided	Friday/Saturday peak hour	9963
EVENT DAY	Guided Unguided	Spring Festival/National day peak hour	19800
EVENT DAY - FUTURE	Guided Unguided	20 % increase in event day demand during peak hour	23760
MEGA EVENT DAYS	Guided Unguided	50 % increase in event day demand during peak hour	29700

The destinations for the evacuation scenarios were determined based on the assembly areas as shown in Figure 4. The assembly areas marked are as per the designated assembly areas mentioned in the Souq Waqif evacuation plans displayed in the Souq corridors. For simulation, the pedestrians were assumed to evacuate to the designated assembly areas considering the shortest path for evacuation. Efficient guiding will improve the evacuation of pedestrians and also prevent anxiety, panic, and blind following of people during panic situations (Ma et al., 2017; Ma et al., 2016; Ren et al., 2021; Zhou et al., 2019). Therefore, in this study, the various demand scenarios for the unguided situation are compared with guided scenarios to evaluate their effectiveness.

Fig. 4: Simulated area of Souq Waqif showing the designated assembly areas

2.3 Simulation

The simulation of crowd evacuation for Souq Waqif has been carried out using PTV Viswalk, which is a microscopic simulation tool for pedestrian traffic (PTV, 2015). The Social Force Model developed by Helbing and Molnar is the basis of pedestrian behavior in Viswalk (Helbing & Molnar, 1995). This continuous model based on the concept of Newtonian Mechanics is capable of qualitatively reproducing many self–organizing phenomena. The global pedestrian walking behavior parameters can be assigned depending on the characteristics of the pedestrians being modeled. The default values represent a moderate conservative average value of an adult pedestrian (Alexandersson & Johansson, 2013). These parameters affect the route choice of pedestrians. They are based on the impact caused by other pedestrians and the relaxation time which determines the aggressiveness of the pedestrians. For the evaluation of various scenarios, the default walking parameter values have been used. Each pedestrian in Viswalk is assigned a destination and the pedestrian always chooses the quickest path to the assigned intermediate or final destination. The dynamic potential option can be utilized to model the pedestrian movement more realistically by making each pedestrian recalculate the path with the least travel time at each time step. The calculation for the dynamic potential option requires high computing capacity and has been thus utilized only for 75% of the routes in the present study.

2.4 Sensitivity Analysis

The social force model used in Viswalk suggests indirect forces that are psychological in nature exerted by the personal environment of the pedestrians and are a measure of the motivation of the pedestrians to perform a certain movement (PTV, 2015). This model is devised in such a way that (a) most of its parameters cannot be measured directly, (b) many characteristics of walking behavior are affected by a single parameter, and (c) more than one parameter determines a single walking behavior (Kretz et al., 2018). This makes calibration difficult. However, a sensitivity analysis was carried out by varying some of the Walking Behavior parameters of Viswalk. The parameters considered for the sensitivity analysis were Asocio mean and Bsocio mean where the parameter Asocio mean decides the strength of the force between pedestrians and the parameter Bsocio mean determines the range of the force between pedestrians in meters (PTV, 2015). Table 2 shows the default values as well as the values used for analysis. The values were increased and decreased by 50% for the analysis and were done for the evacuation of the event day scenario with 19800 pedestrians during the peak hour.

Table 2: Sensitivity analysis parameters and values

Walking Behavior Parameter	Value
ASOCIO MEAN	0.2
	0.4 (Default)
	0.6
BSOCIO MEAN	1.4
	2.8 (Default)
	5.6

3 Results

3.1 Analysis of Evacuation Scenarios

Evacuation scenarios as mentioned in Table 1 were simulated using Viswalk for the Souq Waqif. Figure 5 shows a comparison of the percentage of evacuation with time for varying demands for the unguided as well as guided scenarios. The time required to evacuate more than 98% of the crowd was compared for different scenarios. It can be visualized from Figure 5 that the guided evacuation provides faster evacuation for all the scenarios. Moreover, this tendency is very predominant for higher demand as seen in the Mega event days scenario. Table 3 shows the difference in evacuation time for each scenario. There is a reduction of 180 seconds for the Mega Event Days Scenario and a reduction of 130 seconds for the Event Day scenario while comparing the guided and unguided scenarios. Figures 6 and 7 show screenshots of guided and unguided evacuation scenarios at 300 seconds of simulation. It can be observed that the crowd densities are relatively lower in the guided scenario. It was noted that the route choices made for the unguided scenarios for the varying demand conditions were similar. This is in line with the findings of (Abdelaal, 2020). Moreover, eight locations were identified as potential bottlenecks for unguided scenarios. Some of these locations are wide corridors that are blocked due to the herding effect of the pedestrians. Similar bottleneck locations were identified in the guided scenario. However, the bottlenecks were cleared at a faster rate as some of the pedestrians used alternative routes to the guidance provided. Thus trained leaders as suggested by Zhou et al. (2019) could help redirect the evacuating pedestrian to routes that are insufficiently used.

Table 3: Comparison of evacuation time for different scenarios

Scenario	Conditions	Number of pedestrians/ hr (Demand)	Evacuation time for 98% evacuation (seconds)
Normal Day	Unguided	9963	300
	Guided	9963	280
Event Day	Unguided	19800	530
	Guided	19800	400
Event Day - Future	Unguided	23760	605
	Guided	23760	490
Mega Event Days	Unguided	29700	740
	Guided	29700	560

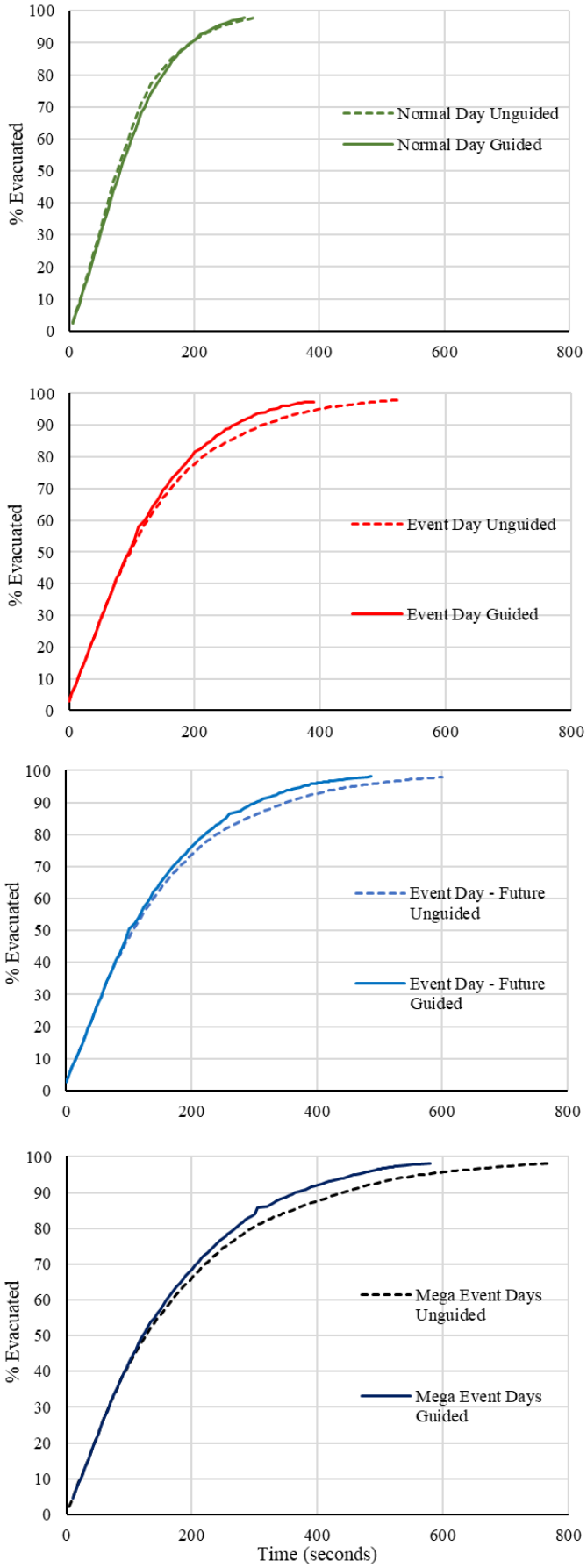

Fig. 5: Comparison of evacuation time for all scenarios

(a)

(b)

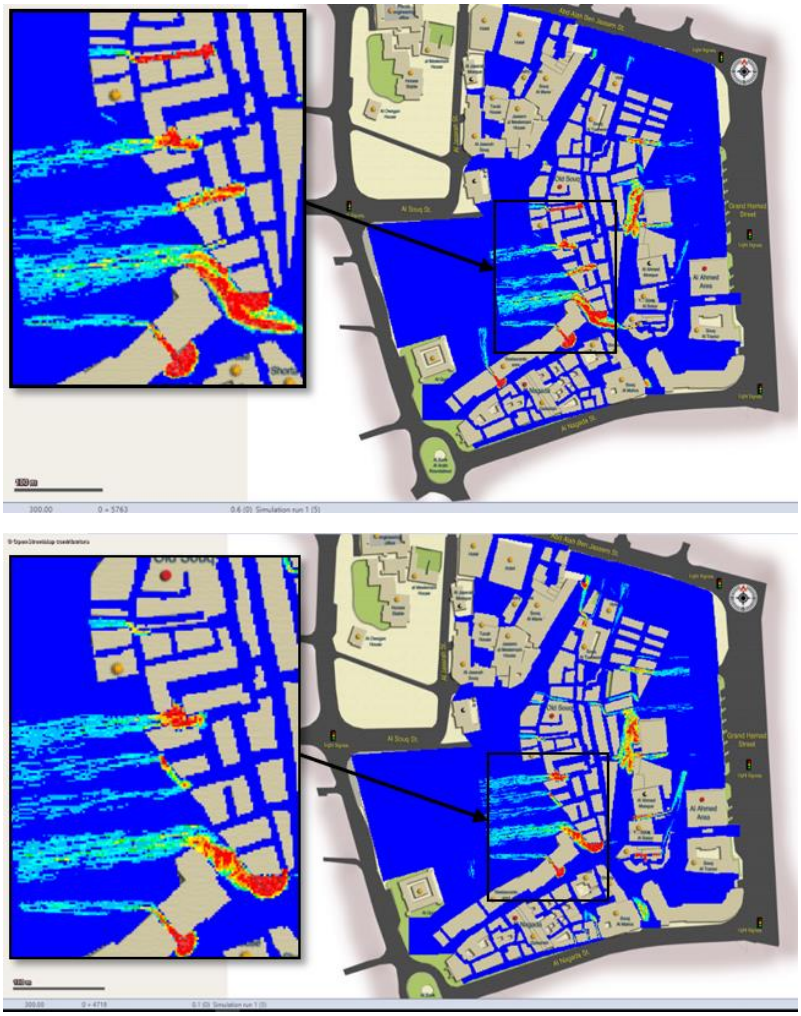

Fig. 6: Unguided scenario (a) and guided scenario (b) at 300 seconds of evacuation showed that the evacuation is proceeding with higher efficiency in the guided scenario

3.2 Sensitivity Analysis

The sensitivity analysis for the simulation of the event day scenario for the walking behavior parameters Asocio mean and Bsocio mean was performed to assess the effect on the evacuation performance. Figures 7 and 8 show the variation in the percentage evacuated at 400 seconds of simulation. Both the parameters show a decrease in the percentage evacuated as the parameter values are increased. However, the simulation model is more sensitive to the values of Asocio mean than Bsocio mean. This is extremely important as these parameters vary for different ethnicity. Further research is necessary for calibrating the parameters for the characteristics of people in Qatar.

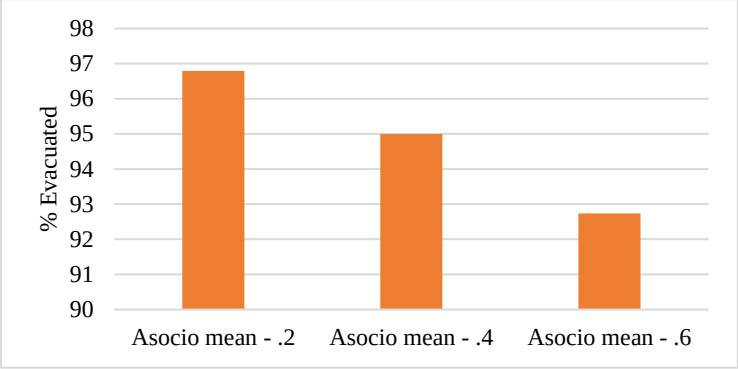

Fig. 7: Comparison of percentage evacuated at 400sec of evacuation time for different values of Asocio mean

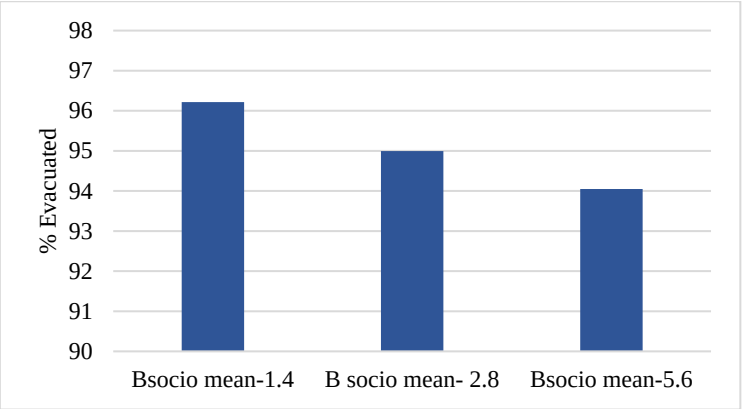

Fig. 8: Comparison of percentage evacuated at 400sec of evacuation time for different values of Bsocio mean

4 Conclusion

The crowd evacuation at Souq Waqif for different scenarios namely normal day, event day, future event day, and mega event days scenarios were simulated using PTV Viswalk crowd simulation software. The evacuation times for 98% of pedestrians evacuating for the various scenarios for guided and unguided conditions were compared. Eight potential bottleneck locations were identified from the simulation. It was found that the guided scenario substantially reduced the evacuation times and this was more predominant for higher pedestrian demand and density conditions. Thus an efficiently designed guiding system that comprises variable message signs or security staff to guide crowds, would help enhance efficiency in crowd flows and reduce injuries and fatalities in case of an emergency. Further, as understood from the sensitivity analysis both behavior parameters, i.e., Asocio mean and Bsocio mean show a decrease in the percentage evacuated as the parameter values are increased. These parameters could be significantly different for different ethnicities and are required to be calibrated using field data to improve the accuracy of the output of the model. Simulation models with actual empirical data as well as walking behavior parameters would provide more realistic results.

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