# Regulating Access to El-Salam Gate in the Prophet's Mosque at Peak Times During Holidays using Simulation

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## Abstract

Crowd simulations have been always essential tools that help in developing and understanding of crowd risks and safety for many of the world's largest events. Regulating the access to El-Salam gate in the Prophet's Mosque at peak times during holidays is a complex crowd dynamics analysis problem that requires special attention. Every day, thousands of visitors are keen to visit the Prophet and, consequently, need access to the El-Salam gate in order to start their visit. Computer simulation can be utilized as an important research tool in understanding the complexity of crowd dynamics across such a wide space. Simulating crowds' behavior in such a large-scale and in a complex environment presents a variety of challenges in representing the interrelated processes that characterize real-world interaction. This paper focuses specifically on the problem of simulating the dynamics of large, dense crowds in the area of El-Salam gate. Such crowds exhibit a low interpersonal distance and a corresponding loss of individual freedom of motion. Three different 3D simulating models are presented where concurrent groups of simulated agents interact in a modeled environment of El-Salam gate area with potential to enable direct acquisition of statistics and indications at levels of detail and accuracy. A series of simulation results are carried out for each scenario, in order to reflect the behavior of each model and to assess its effectiveness in improving the gate accessing process.

Keywords: crowd simulation, environment representation

## Introduction

Over the past decades, a wide range of crowd simulation systems have been developed and applied to crowd safety for many of the world's largest events. Crowd simulations have been always essential tools that help in developing and understanding of crowd risks [1,2,3,4]. Methods of assessing crowd density and understanding of the rates at which spaces can fill is vital in order to understand and avoid dangerous overcrowding. To do that, some basic information about the space a moving crowd occupies, the rates at which crowds can move, and the rates at which spaces can fill are needed. One solution has been to use crowd simulations. Moreover, they enabled us to experiment with a wide range of behavioral assumptions. Experimentations with crowds using a computer-generated environment can be conducted in a way that is not possible in real time, to get understanding of the interactions between crowds and their environment [2]. Using crowd simulations enable us to understand how risks develop into incidents and how incidents can escalate into disasters. However, simulation techniques have been expensive and time consuming.

Computer simulation utilizes mathematical models, which describe the crowd dynamics in addition to the way individuals behave in a range of situations [3]. The crowd simulation is limited by the assumptions of the mathematical model. A simulation process would not behave properly if built in an incorrect or unsuitable set of assumptions.

An important feature of crowd density and risk assessment is to determine which areas within the space will be of high density and which areas will be of lower density, and also to determine which areas are going to be standing and static, and which areas are going to be dynamic. For example, entry and exit gates would be predominately of higher density during ingress and egress, but low density at other times. Occasionally, there may not be time to react between the crowd entering the space and the space becoming too crowded. Therefore, real time monitoring and managing crowd flow and crowd density is essential for crowd safety.

Reviewing crowd accidents from around the world, as an example the accidents in [5], shows that deficient planning before events and unsatisfactory risk management during events are the common causes to major incidents and are the key points of failure.

Many research have been conducted to study the services presented in Al-Masjed Al-Nabawi [6,7]. Regulating the access to El-Salam gate in the Prophet's Mosque at peak times during holidays is a complex crowd dynamics analysis problem that requires special attention. Every day, many hundred thousands of visitors are keen to visit the Prophet and, consequently, need to access the El-Salam gate in order to start their visit. Computer simulation can be utilized as an important research tool in understanding the complexity of crowd dynamics across such a wide space. Simulating crowds' behavior in such large-scale and complex environment presents a variety of challenges in representing the interrelated processes that characterize real-world interaction.

A Major event, like visiting the Prophet's mosque at peak times during holidays, require a significant amount of planning. This process engage a wide range of organizers, such as the emergency services, local authorities, and security authorities. During such special events, careful review of the risk analysis is critical; any risks missed during the planning process must be identified. If planning phase neglects risk assessment, risks may be realized during the operational phase of the event.

Crowd risk analysis should include the necessary examination of spaces for both static (standing) and dynamic (moving) crowds. These are spaces such as queuing systems, entry points, exit points, emergency access, etc. There is also a need for crowd monitoring and continual risk assessment during the operational phase of the event, for example, assessment of crowd flow rates for congestion during queuing, at entry points, congestion in critical locations, and whether the system is performing as planned.

This paper focuses specifically on the problem of simulating the inter-agent dynamics of large, dense crowds in the area of El-Salam gate. Such crowds exhibit a low interpersonal distance and a corresponding loss of individual freedom of motion. Three different 3D simulating models are presented where concurrent groups of simulated agents interact in a modeled environment of El-Salam gate area with potential to enable direct acquisition of statistics and indications at levels of detail and accuracy. A series of simulations are carried out, for each scenario, in order to reflect the behavior of each model and to assess its effectiveness in improving the gate accessing process.

The paper is organized as follows. Section 2 discusses problem description and crowd risk analysis. Section 3 describes the proposed scenarios. In Section 4, simulation results are presented. Finally, conclusions are drawn in Section 5.

## Problem Description

To control entry to a gate, some sort of barrier or fence should be put around the site. The crowd needs to access the gates and leave the masjid area by another gate after the visit has finished. The entry and exit points will be of limited throughput, and they need to be of sufficient capacity to minimize the risk of crushing on entry or exit. These entry/exit points affect the rate of fill, and if the high-density areas fill too quickly the situation becomes of high risk.

### Crowd Risk Analysis

For the crowd risk analysis, there are several considerations: site capacity, movement pathways, entry and exit systems, and facilities management during normal and emergency situations.

*Site capacity:* is typically calculated based on the available area, the suitability of that area, and the rates of evacuation in an emergency. Site capacity is also based on physical and safety considerations for a site. International guidance recommends assessment of entry rates as an important safety factor that may reduce the overall site capacity if not sufficient to meet the arrival profile of the crowds.

*Movement pathways:* Arrangements that result in unbalanced use of entry or exit routes, dead ends, or similar confusing pathway choices, are not acceptable. Equally balanced entry and exit points are preferred over a single centralized location.

*Entry and exit points:* If the arrival flow rate exceeds the entry system capacity, then a queue will develop. In other words, people arriving at the back of the queue arrive more quickly than the people enter at the front of the queue (the people nearest the entry system). This results in a gradual build-up of crowd density (people per square meter) over time. As the crowd/queue size grows, the density at the front part of the queue will be compressed. This increases the crowd density (people per square meter) and exposes the crowd to risk of crushing. As crowd density increases to above six or seven people per square meter, the crowd reaches a point at which individuals experience physical contact and pressure. Continuous exposure to this pressure affects the crowd behavior, and there is an inherent risk to life. Those individuals at the front of an entry system queue can become trapped. They cannot remove themselves from the system, as the back of the queue is moving towards the entry point.

<u>Crowd Flow to El-Salam Gate</u>

During holidays, at peak times, regulating the access to El-Salam gate requires special attention. In order to control entry to that gate, some sort of barrier or fence is put around the site. The entry and exit points will be of limited throughput, and they need to be of sufficient capacity to minimize the risk of crushing on the entry point. The usual setup of fence that is used for controlling crowd flow is shown in Fig. 1.


Fig. 1: The fence that is put around El-Salam gate site for controlling crowd flow.

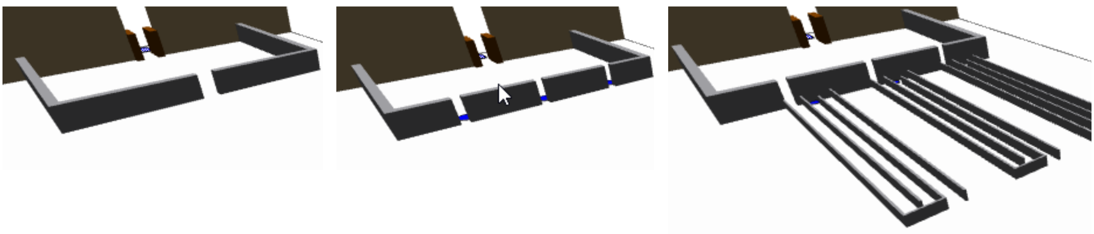
## Proposed Scenarios

As mentioned earlier, in order to control entry to El-Salam gate, some sort of barrier or fence is put around the site. Accessing the closed fence (shown in Fig. 1) is controlled through a doorway (or more) in the front side of the fence.

Three different 3D simulating models are presented, where concurrent groups of simulated agents interact in a modeled environment of El-Salam gate area with potential to enable direct acquisition of statistics and indications at levels of detail and accuracy. The three scenario are as follows:

- Scenario 1: the front side of the fence has one doorway of width 2 m., as shown in Fig. 2-a; this is the usual scenario that is already used.
- Scenario 2: the front side of the fence has three doorways, each of width 1 m, as shown in Fig. 2-b.
- Scenario 3: the front side of the fence has three doorways, each of width 1 m and are accessed through a zigzag-shaped track (3 sides) of length 30 m and width 1.5 m, as shown in Fig. 2-c.

The behaviors of these scenarios are examined in the next section.



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3

Fig. 2: Three different scenarios for controlling crowd flow to El-Salam gate.

## Simulation Results

A series of simulations are carried out, for each scenario, in order to reflect the behavior of each model and to assess its effectiveness in improving the gate accessing process. Experiment time, for each simulation is 16:40 min, while the total number of agents that entered the simulation session is 10000 persons (i. e., 600 person/min).These 10000 persons are uniformly distributed on the available doorways. Some simulations results of the three aforementioned scenarios are calculated; these results include:

- Crowds' distributions after several time intervals (2 min, 4 min, and 6 min), in 2D and 3D,

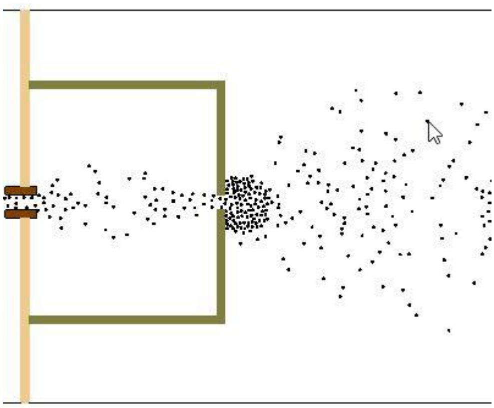
- Average density per time interval,
- Travel time statistics.

Results of Scenario 1:

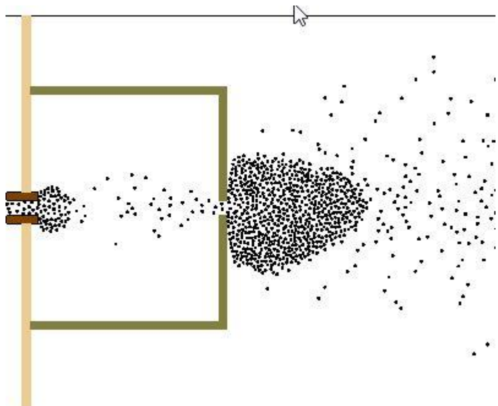
The calculated statistics are listed in Table 1, while simulation results are shown in Fig. 3.

Table 1: The calculated statistics of Scenario 1

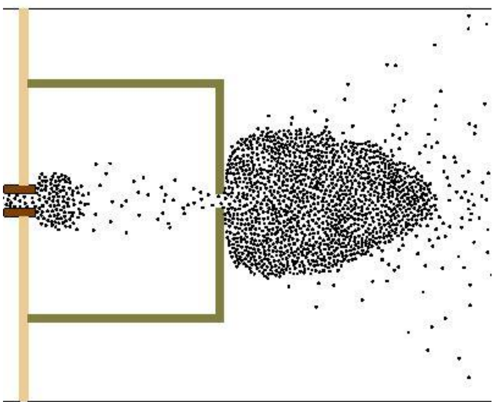
| | |
|---|---|
| Experiment time | 00:16:40 |
| Total number of agents | 10000 |
| Number of agents reached the destination | 2135 |
| Average travel time | 00:07:13 |
| Maximum travel time | 00:14:35 |
| Minimum travel time | 00:01:31 |



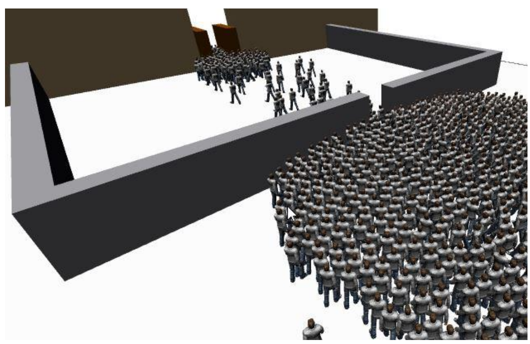
**(a) Crowds distribution after 2 mins.**



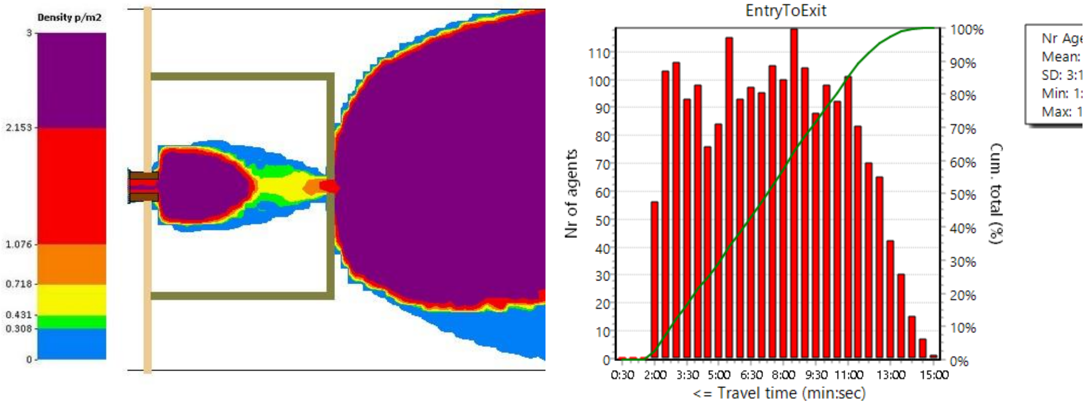
**(b) Crowds distribution after 4 mins.**



**(c) Crowds distribution after 6 mins.**



**(d) Crowds distribution after 6 mins, in 3D.**




**(e) Average density per time interval** **(f) Travel time statistics**

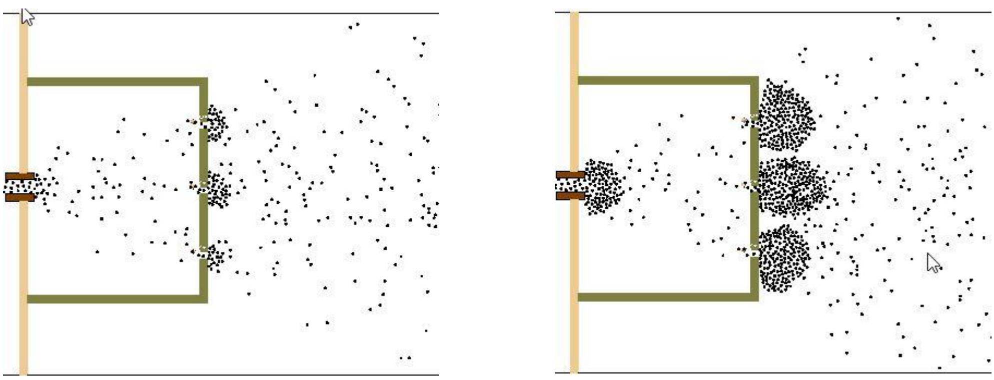
Fig. 3: Simulation results of Scenario 1

<u>Results of Scenario 2:</u>

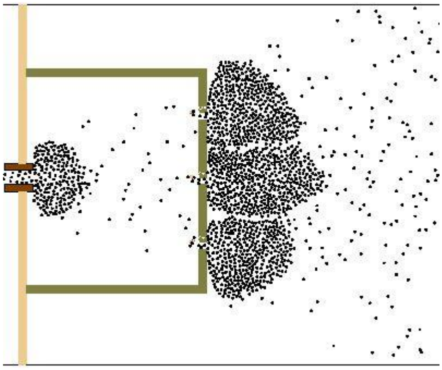
The calculated statistics are listed in Table 2, while simulation results are shown in Fig. 4.

Table 2: The calculated statistics of Scenario 2

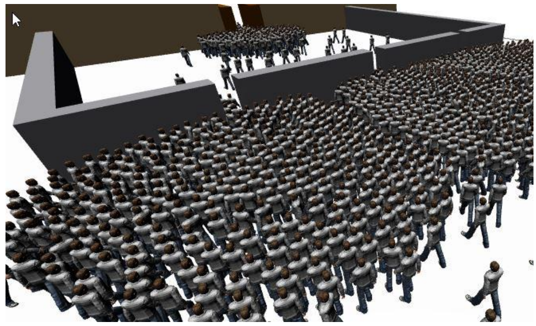
| | |
|---|---|
| Experiment time | 00:16:40 |
| Total number of agents | 10000 |
| Number of agents reached the destination | 2159 |
| Average travel time | 7:13 |
| Maximum travel time | 15:00 |
| Minimum travel time | 1:30 |



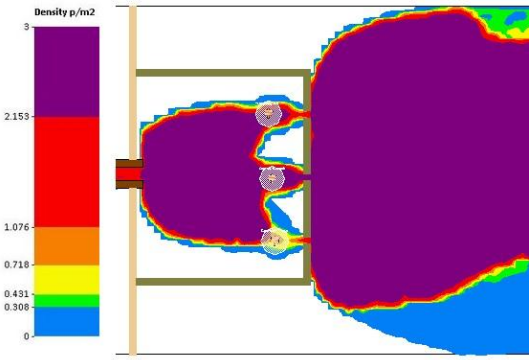
**(a) Crowds distribution after 2 mins.** **(b) Crowds distribution after 4 mins.**



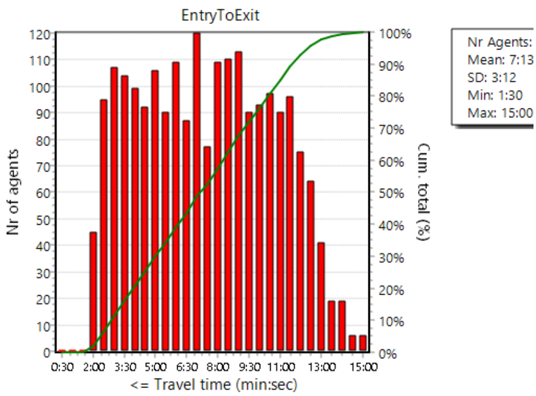
**(c) Crowds distribution after 6 mins.**



**(d) Crowds distribution after 6 mins, in 3D.**




**(e) Average density per time interval**




**(f) Travel time statistics**

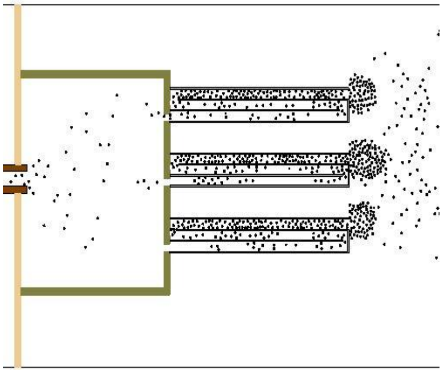
Fig. 4: Simulation results of Scenario 2

<u>Results of Scenario 3:</u>

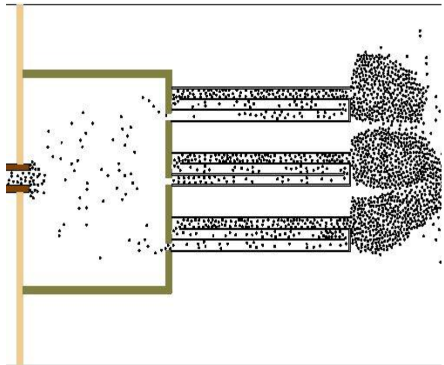
The calculated statistics are listed in Table 3, while simulation results are shown in Fig. 5.

Table 3: The calculated statistics of Scenario 3

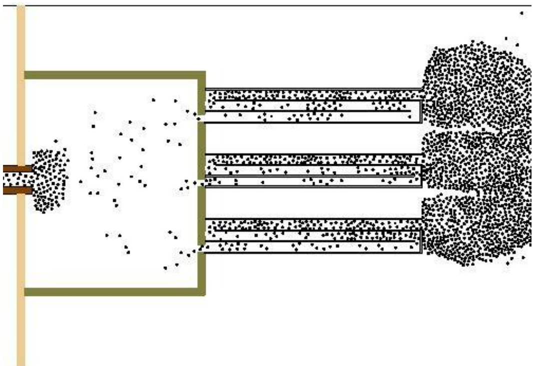
| | |
|---|---|
| Experiment time | 00:16:40 |
| Total number of agents | 10000 |
| Number of agents reached the destination | 2005 |
| Average travel time | 00:07:48 |
| Maximum travel time | 00:14:58 |
| Minimum travel time | 00:02:19 |



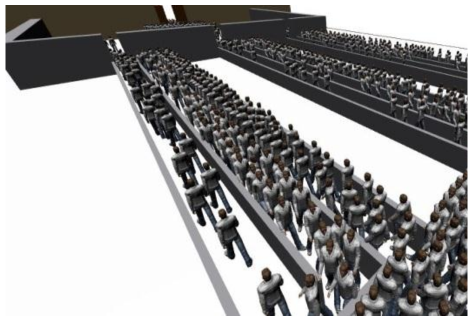
(a) **Crowds distribution after 2 mins.**



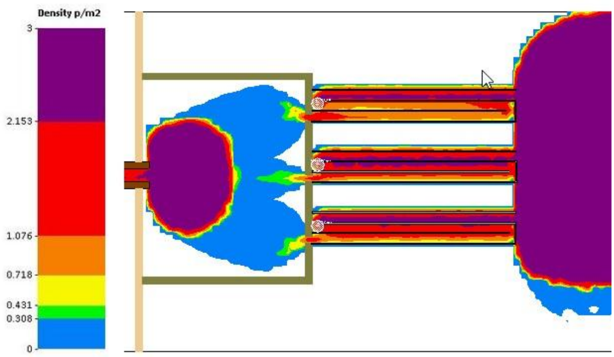
(b) **Crowds distribution after 4 mins.**



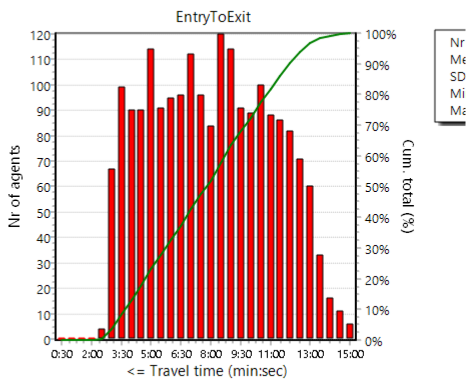
(c) **Crowds distribution after 6 mins.**



(d) **Crowds distribution after 2 mins, in 3D.**




**(e) Average density per time interval**




**(f) Travel time statistics**

Fig. 5: Simulation results of Scenario 3

As crowd density increases, the crowd reaches a point at which individuals experience physical contact and pressure. Continuous exposure to this pressure increases risk to life. Those individuals at the front of the doorways can become trapped. They cannot remove themselves from the system, as the crowds are moving towards the entry point.

It can be seen from the aforementioned results that, in order to keep the queue (crowd density) small at the entrance of El-Salam gate, the crowd flow rate to the closed fence in its area should be controlled. This can be achieved by using the arrangement of Scenario 3, which can keep the high density of crowds away from the front of the doorways area. This can also provide a certain degree of safety when the arrival flow rate exceeds the capacity of the entry system at entrances of the zigzag-shaped tracks.

## Conclusions

In this paper a simulation of the problem of the dynamics of dense crowds in the area of El-Salam gate has been presented. Three different 3D simulating models have been discussed where concurrent groups of simulated agents interact in a modeled environment of El-Salam gate area with potential to enable direct acquisition of statistics and indications at levels of detail and accuracy. A series of simulation results are carried out, for each scenario, in order to reflect the behavior of each model and to assess its effectiveness in improving the gate accessing process. The simulation results showed that Scenario 3 can keep the crowd density low at the entrance of El-Salam gate, while providing a certain degree of safety at entrances of the zigzag-shaped tracks.

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