A Simulator to Improve the Pilgrims Performance in Stoning Ritual in Hajj

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Summary
With the significantly increase in the number of pilgrims in Hajj, There is a need for more researches to propose an efficient and new improvements for Hajj activities. One of these activities is the stoning. Stoning is a critical process in Hajj in which hundreds of thousands of pilgrims accumulate around the Jamarat basin in specific hours in the day. In stoning, there is an increase in accident probably. This huge crowd needs high control. In this work, the authors simulate stoning in Hajj to find the relationship between the Jamarat basin length and the pilgrims' stoning performance and the impact of organizing the pilgrims in three rows around the Jamarat basin. The authors use a crowed management simulation tool "STEPS". From the results of the simulation, it is found that increasing the Jamarat basin length by 20% will improve the pilgrims' performance in stoning process by 25%.

Key words:
Crowd management Simulation tools, Stoning in Hajj, Al Jamarat Bridge.

1. Introduction

In Hajj, millions of pilgrims gather in the area of Al Jamarat Bridge which is a special pedestrian's bridge in Mina. This gathering may cause serious situations, because all the pilgrims need to do stoning ritual in a specific time afternoon. The safety and comfort of Hajj has become a major concern, especially after the incident occurred during the stoning of the devil ritual in Jan 2006, when at least 346 pilgrims were died and at least 289 more were injured. Hence, decreasing the density of the pilgrims near the Jamarat bridge is a critical issue. After a lot of work, the Ministry of Municipal and Rural Affairs in Saudi Arabia, has finished developing a four-storey Jamarat Bridge to accommodate four millions of pilgrims per day. Using simulation of the pedestrians that trying to get a certain service can help in making some decisions to decrease the pilgrims density. A brief review of some related works about crowd simulation which are related to stoning ritual problem has been done. Some of them use continuum based models for crowd dynamics which is also conducted in this study.

In [1], the authors present an approach that unifies global path planning and local collision avoidance into a single optimization framework. People in this model do not experience a discrete regime change in the presence of other people. Instead, they perform global planning to avoid both obstacles and other people. This dynamic potential field formulation also guarantees that paths are optimal for the current environment state, so people never get stuck in local minima which aren't acceptable in this system.

In [2], the authors discuss how one may study high density conditions based on suitable video data. This paper addresses the measurement process and safety-relevant features of the speed-density and flow-density diagrams. The correct conclusions from the video data can be drawn by analyzing the video data and can determine critical crowds. This study also shows in detail how certain problems related to video based evaluations can be successfully overcome and how the results depend on the specification of parameters.

In [3], in this study a digital model of AL-Haram is designed to be used in educational sessions and crowd simulations by using 3D digital modeling. Crowd simulation framework in this study implements a multi-agent system and least effort goals. The algorithm in [6] is used for this framework.

In [4], this approach focuses on Multi-Agent Navigation in crowd; it's integrated the pre-computed roadmap for global path planning and the Reciprocal Velocity Obstacles for local navigation and collision avoidance in a single navigation framework.

In [5], the authors present an approach using continuum based models for crowd dynamics. This approach combines global and local planning in a single optimization-based framework, and gives compelling results for many kinds of crowds taking into account environmental obstacles. However, this approach considers waiting or staying in the system as an

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environmental obstacle, which is a main point in the current system (Jamarat stoning).

In [6], the authors focus on the factors that affect the motion of the pedestrian. They also shows how to avoid the difficulties in discrete simulation of individual by using continuum formulation. This study considers the motion of crowds as a continuum, with equations specifically derived for this purpose. However this approach is suitable for medium- density crowds not for high-density where people are very closely packed and tend to come into contact.

In [7], this study is developed of a continuum, or macroscopic model, it present a model for the flow of pedestrians that describes features typical of this flow, such as the fall due to panic in the outflow of people through a door.

In [8], this study presents a new algorithm to generate energy-efficient trajectories for crowed simulation, it computed a biomechanically energy-efficient trajectory for each individual in a multi-agent simulation, and it based on principle least effort.

However, the present work adds a study of the relationship between the performance of the pilgrims' stoning and the length of the Jamarat. The authors try to improve the stoning process through increasing the length of the basin and organize the pilgrim movement.

The rest of this paper is organized as follows: In Section II, the analysis, conceptual model and specification model are presented. In Section III, the results are demonstrated. In Section IV some recommendations are given. Finally, Section V concludes this work..

II. Analysis

a. Conceptual Model

In simple words, Al jamarat stoning process is one of the riskiest processes during Hajj. The meeting of hundreds of thousands pilgrims in one place, at the same time, performing the same ritual undoubtedly result in severe congestion and accidents unless search in ways that contribute to the management of these crowds and constant improvements to facilitate the flow of the pilgrims.

The current study aims to build a simulation models for the process of stoning in the real situation and after some improvement in Al jamarat basin length, to evaluate this proposal and ensure its effectiveness and recommend an enhancement which will contribute in the ease of the stoning process.

The authors assume that there are five types of pedestrians adult, child, old, fat and tall. The Characteristics of each type are shown in the table [1].

Table [1]: The Characteristics of types of pedestrians

Type	Width	Height	Color	Max speed	Patience
Adult	0.40	1.80	Red	1.20	0.50
Child	0.40	0.50	Blue	1.00	0.00
Old	0.40	1.80	Yellow	0.30	1.00
Fat	1.00	1.80	Green	0.60	0.70
Tall	0.40	2.50	Black	1.50	0.20

The authors believe that there is two main factors that will enhance the performance of Aljamarat Stoning Process: the length of the basin and the organize of the pedestrians (pilgrims).

The authors assume that in every meter there are 3 pilgrims and there are 3000 pedestrians and they are added at the beginning of the simulation but they will not start moving straight away. They will wait between 0 and 16 minutes before doing so (It is a uniform Distribution and has a mean of 500 and a variance of 1000 i.e. it goes from 500-1000/2=0 to 500+1000/2=1000). In the 3000 pedestrians there are 0.50 adult, 0.10 children, 0.20 old, 0.10 fat and 0.10 tall. The authors assume that the length of Al jamarat basin is 20 meters, this mean that there are [(20*3 =60) and (60*2 =120)] i.e. 120 random service places “where the pilgrim can stone the basin” per side (left and right) and (2*2 =4) i.e. 4 random service places (top and bottom) at a time, So the total numbers of service places are 248 places in the real situation model.

The authors made three models to test the effectiveness of their proposal:

In the first enhanced model (which tests the effect of increasing the length of the basin) then add 20% to the length of the basin ,As a result the length of the basin becomes 24 meters , [(24*3 =72) and (72*2 =144)] i.e. 144 random service places” per side (left and right) and (2*2 =4) i.e. 4 random service places (top and bottom) at a time , So the total numbers of service places are 296 places.

In the second enhanced model (which tests the effect of organizing the pilgrims) the authors assume that three rows per side can the pilgrim takes any place of these rows to stone the basin.

The length of the basin becomes 20 meters , [(20*3 =60) and (60*3 =180)] i.e. 180 service places” per side (left and right) and (3*2 =6) i.e. 6 service places (top and bottom) at a time , So the total numbers of service places are 372 places (10 of them is not active “In case of so tall pilgrim comes first and in next row short pilgrim will not be able to stone) .

In the third enhanced model (Which combines both first and second enhanced model).

The length of the basin becomes 24 meters and there are three rows per side, [(24*3 =72) and (72*3 =216)] i.e. 216 service places" per side (left and right) and (3*2 =6) i.e. 6 service places (top and bottom) at a time , So the total numbers of service places are 444 places (20 of them is not active "In case of so tall pilgrim comes first and in next row short pilgrim will not be able to stone).

b. Specification Model

This work plan includes building simulation models for the current situation and other simulation models after adding the proposed enhancement. The authors checked the validity of the model by comparing the output of the real current model and the output of the enhancement models.

The authors use a crowed management simulation tool called "STEPS", which is a state-of-the-art micro-simulation tool for simulating pedestrian dynamics under both normal and emergency conditions. The analysis of people movement is rapidly becoming a requisite in the design and operation of many types of facilities. Using STEPS to optimize people movement can reduce the cost of building design, provide a more agreeable environment, assist emergency egress management and maximize retail potential.

One key feature of the STEPS tool is that it is based upon fundamental principles of people movement which are clearly stated in full so that users can make informed choices concerning the correct inputs for their application.

STEPS employs a modern agent-based approach which predicts the movement of discrete individuals (virtual people) through three-dimensional space. This is in contrast to the older generation of pedestrian models, such as Pedroute, which treat the problem as one of a continuum flow. The major advantages of agent-based models are that they give a more realistic representation of pedestrian movement and allow the elucidation of subtle but important details of pedestrian movement, thereby giving much greater insight to the designer.

To show the effectives of their proposal the authors test 4 models

- Model "A" that simulate the current real situation of Al jamarat basin.
- Model "B" with increases the length of the basin by "20%".
- Model "C" with the same basin length but with three rows for serving "which mean two persons behind the nearest person to the basin can stone the basin".
- Model "D" with combines both Model B and Model C.

A screenshot in Figure(1) is illustrate model "B" and "C" through running on "STEPS".

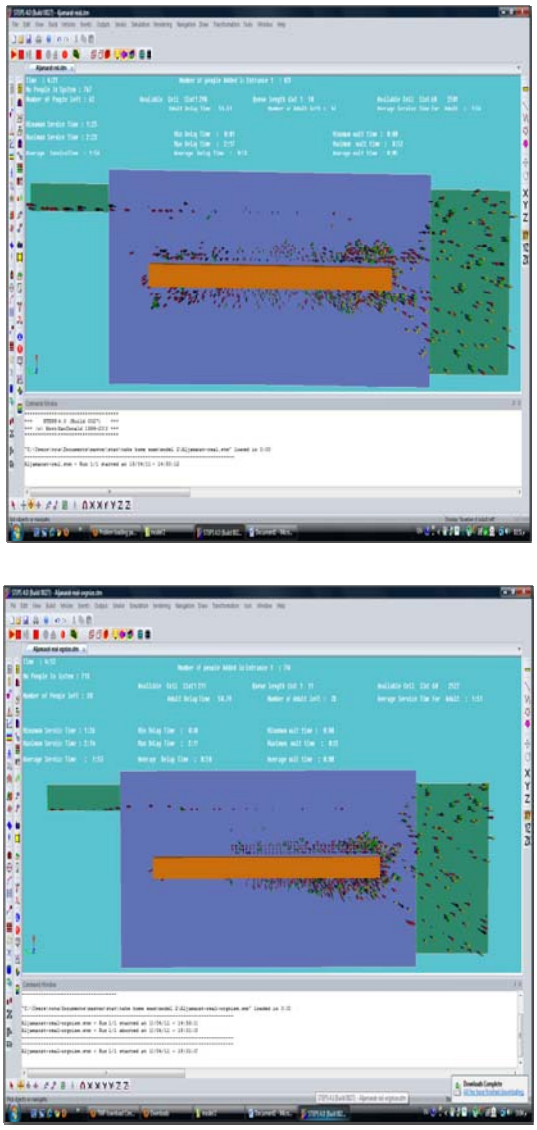

Figure (1) is illustrate a screenshot for model "B" and model "C"

III. Results

After running the above four models using "STEPS", the authors observe the output and extract the following information shown in Table (2).

In Table(3) the authors demonstrate the same output in Table(2) but in minutes to facilitate the output reading and the time unit is in minute.

As observed from Table (3), the three models (B,C,D) enhanced the average of waiting time comparing with

model A which represent the real current model. However, from the previous table it is obvious that when increasing the length of the basin by 20%, the average of service time will decrease by approximately 18% , Average Delay Time will decrease by 22% and Average Wait Time will decreased by 25% .Model B give the best result comparing with the other models which represents the increasing of the basin length by 20%.

Table (2): The output of the running models in seconds

Model	Time	Avg Delay Time	Avg Waiting Time	Adult Delay Time	Adult Avg Service Time	Average Service Time
Model A	44:23:00	416.6	461.56	337.05	425.53	641.98
Model B	39:53:00	324.6	343.85	264.9	324.07	528.69
Model C	43:06:00	460.73	352.93	418.59	435.74	590.71
Model D	43:56:00	453.14	347.1	403.45	424.34	598.04

Table(3): The output of the running models in minutes

Model	Time	Avg Delay Time	Avg Waiting Time	Adult Delay Time	Adult Avg Service Time	Average Service Time
Model A	44:23:00	6.94	7.69	5.62	7.09	10.70
Model B	39:53:00	5.41	5.73	4.42	5.40	8.81
Model C	43:06:00	7.68	5.88	6.98	7.26	9.85
Model D	43:56:00	7.55	5.79	6.72	7.07	9.97

IV. Discussion and Recommendation

From the above results it is concluded that the length of the basin has an effect in improving the performance of the pilgrims in stoning process, (Model "B") is 25% better than the real current situation .On the other hand, the effect of organizing the pilgrims in three rows (Model "C") is 23% better than the real current situation . So, it has less effect than the effect of increasing the basin length .Whilst, using the two factors increasing the basin length and the organization of the pilgrims (Model "D") is 24% better than the real current situation .But it gives less improvement than Model "B". So the authors recommend Model "B".

V. Conclusion and Future Work

In this work, the authors study how to improve the performance of the pilgrims in stoning process in Hajj by designing four models using a crowed management simulation tool "STEP". The first model simulates the real situation of the stoning with assuming the basin length equal 20m, the second model the author increase the length of the basin by 20%, the third model assume an organization in which the pilgrims can stone the basin from three rows around it, and in the last model the authors assume the 20% increasing in the basin length beside the organization of the pilgrims in which they can stone the basin from three rows.

After running the models, the results show an improving in the last three models when comparing with the first one. Furthermore, the second model gives the best improvement by 25% comparing to the real current situation of the stoning.

For the future work, the authors will conduct a study to compare which is the best decision adding more stores to the bridge or make an increasing in the basin length. Also more researches are needed to solve another ritual related to Hajj like 'Tawaff".

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