Evaluation of Existing Software for Simulating of Crowd at Masjid Al-Haram

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Abstract – *Crowd simulation has played an important role in solving situations such as building evacuation, crowd congestion, and pedestrian analysis. In order to improve the crowd congestion problem within and the surrounding area of the Masjid Al-Haram, we need a tool which could reproduce specific scenarios and study the possible controls that could ease the problem. This paper explains the criteria to be considered in evaluating the crowd simulation software for the Masjid Al-Haram under both, normal and emergency situations. Our study has led us to the most suitable software package that meets our requirements. We have also identified the main features that we should (later) incorporate in our own design of the simulation system of the Masjid Al-Haram.*

Keywords: Crowd simulation, Hajj, Masjid Al-Haram, dense crowd.

1 Introduction

It is estimated that more than two millions people make their pilgrimage to Mecca to perform Hajj. During their pilgrimage, the pilgrims perform a number of religious acts such as circling the Kaabah (known as Tawaf), go back and forth between Safa and Marwah hills (Saie), "wuquf" at Arafah, over night at Muzdalifah and stoning the devils at the Jamarat. Since the rituals are bounded by time and also space the crowd can be uncontrollable and at times leading to some form of tragedy, for example the stoning at the Jamarat. However, after the new Jamarat design and management, the safety of the pilgrims is much more secured. Following the success of the Jamarat project, there is a need to provide better crowd control at the Masjid Al-Haram. The purpose of our work is to study the issues pertaining to the control and management of the crowd within and also the surrounding area of the Masjid Al-Haram by means of an existing software simulation study.

Software on crowd simulation has been developed and used in many situations such as the study on evacuation, congested areas of mass crowd, and also in crowd animation in entertainment industries. Modelling and simulation of crowd at the Masjid Al-Haram is unique in itself since it includes modelling of the specific movement in a specific area of the mosque, for example, the Tawaf area, where the pilgrims must move in a circular motion in an anti-clockwise direction. For the Saie area, the crowd go back and forth between Safa and the Marwah, in seven laps. The software we choose should be able to simulate such movements. Features such as path design capabilities will help us in this regard. Another important criterion is the size of the crowd. We estimate that around 50,000 pilgrims (or pedestrians) may be present in the Tawaf area, especially during the peak period such as the Hajj.

This paper is organised as follows; section 2 discusses the two main categories of the crowd simulation software followed by the detail description of the software of our interest. In section 3 we present our evaluation framework while the result of the evaluation is discussed in section 4. Section 5 presents a brief discussion on one of the packages that we have tested and section 6 estimates the price of each of the software. Section 7 concludes the paper by highlighting the needs of building our own simulation software for the purpose of simulating the crowd at the Masjid Al-Haram.

2 Existing simulation software

Crowd simulation software can be categorized into two groups, evacuation and normal situation. Evacuation simulation software is used to calculate the amount of time it takes for all pedestrians to exit a building or an area. Such software typically are able to simulate behaviours of pedestrians in emergency situations. The effects of smoke, toxic gases, fire and congestion at exits, on the decision making and movements of pedestrians are important. We may use the results of such simulations to improve the environment geometry for evacuation purposes. Crowd simulation software for normal situations is used to simulate crowd movements in a normal or non-emergency situation. These packages are being used to find ways to improve the environment for more comfortable and faster movement of the crowd.

We initially use the list of crowd simulation software in [1] together with the results based on our Google search. We shortlisted seven of the more popular software packages which passed our criteria – able to simulate more than 10,000 agents, are relatively established and have been used for real situations and in various projects. The seven shortlisted packages are Simulex, PedGo, GridFlow, ASERI, Legion, STEPs and Simwalk.

2.1 Simulex

Simulex is a software system from IES Ltd., UK, designed by Dr. Peter Thompson [15], [21]. Simulex can simulate evacuations of relatively large crowds in complex buildings. The software has been validated in three case studies conducted in New Zealand [4]. The test involved evacuation of three buildings. Evacuation has been carried out in real-life and also using a simulation on the software. Comparison has proven that the accuracy of the software model is acceptable.

It is possible to design and edit environment geometry using the visual editor program that comes with the software. It is also possible to import AutoCAD files into the program. Agents can have different size, speed and movement delay. This program uses the distance maps algorithm to move pedestrians toward the nearest exit [15]. The software provides details of the flow and the total count of pedestrians passing specific exit. Raw data of pedestrian movements (in text data format for use in other software) and visual output are also provided.

2.2 PedGo

PedGo is a simulation software developed by TraffGo HT GmbH, Germany, as a result of a research project called BYPASS by Tim Meyer-König and Dr. Hubert Klüpfel [16]. This software provides a real time simulation of crowd of up to 10,000 people on a 500MHz Pentium 3 computer. PedGo should be able to simulate evacuation of larger crowds using a more powerful computer. It was used to simulate a worst case test of an evacuation scenario of 100,000 pilgrims on the Jamarat Bridge [19].

PedGo editor enables user to edit and modify environment designs. According to the product website, AutoCAD import utility will be provided in the near future. Pedestrians in this software may be assigned with different properties (maximum speed, patience, dawdle and sway) using a normal statistical distribution. Cellular automata model is used to simulate the microscopic or local movements of the pedestrians. Visual output, evacuation time, density plot, walking time and travelled distance for individual pedestrians and raw data of pedestrian movements are among the outputs of the software.

2.3 GridFlow

GridFlow is a product of David Purser from BRE Ltd., UK [1],[7], [8], [22]. This software has been validated on different types of buildings and is intended for simulating crowd evacuation only.

A plan designer is available for preparing environment design information. The ability of importing AutoCAD designs is available via additional software called JOSEFINE. It is possible to specify pre-movement delay and speed distributions for the pedestrians. The program is capable of simulating the effects of smoke, fire and toxic gases in the environment. GridFlow uses a cellular based method for microscopic

movements. Exporting data to Excel software, the number of people in each section at each moment, exit times and visual display (using JOSEFINE) are among the outputs of the software.

2.4 ASERI

ASERI was developed by Dr. Volker Schneider from Integrierte Sicherheits-Technik GmbH, Germany, this software can simulate large amount of agents in complex geometrical environments [9],[23]. ASERI is also intended for evacuation and emergency situations.

This software has both the ability of creating floor plans and import from AutoCAD format. Agents are different from each other with several parameters like size, speed, sex, age, fitness, inability, knowledge of the building, smoke tolerance and individual goals. Mean value of egress time of pedestrians, bottleneck and congestion situations, trajectory line of individual pedestrians and video capture of the simulation are among the outputs which the software provides.

2.5 Legion

The Legion software is developed by Legion International Ltd., UK [17]. This software has gone through years of studies on crowd movement and behaviour. A new version of the software, Legion Studio 2006 is now being offered. The software can simulate thousands of pedestrian on a single PC and it can be used for both evacuation scenarios and normal non-emergency studies.

Legion provides facilities for importing and modifying environment designs. It is possible to specify entrance, exits and routes of movements. In Legion, individual pedestrians decide based on their objectives, may possess different level of knowledge, experience and objectives. They also have perception of their surrounding environment. This model uses a continuous "least effort path" algorithm for the simulation of movements. There are templates available for different types of pedestrians like commuters and tourists.

Throughput data, local density levels, congested areas, time taken for individuals to the destination, raw movement data output, video and pictures are among the outputs that the software is able to provide.

2.6 STEPs

STEPs crowd simulation software is developed by Matt MacDonald from the UK [20]. This software has been validated against NFPA (Standard for Fixed Guideway Transit and Passenger Rail Systems) in two train station case studies [6]. For both cases, STEPs has been able to reproduce evacuation times comparable to NFPA. STEPs has extensive features for simulation of evacuation and also the study of normal pedestrian movements in non-emergency situations. This software is able to simulate tens of thousands of pedestrians on a powerful computer. In addition, STEPs is able to simulate group effects (like families). AutoCAD import is available and one can also design the environment using the software's own design features.

STEPs simulates behaviours and movements of individual pedestrians. It is possible to determine speed details, size, patience level, paths for individual agents. Graphical representation of local densities, usage levels, exit usages, densities in desired regions, total evacuation time, number of pedestrians in each region, disabled and slow pedestrians, track records, raw movement data and visual and video capture of the simulation are among the available outputs.

2.7 SimWalk

SimWalk is a pedestrian simulation software developed by Savannah Simulations AG, Switzerland. This software can be used for normal and evacuation simulation of crowds but the simulation of normal situations has limitations for our purpose. It is only possible to define a start area, way point (middle point) and an exit point for normal mode simulations. SimWalk can model relatively large crowds, and this software is used by several engineering and research institutes. We have been able to use a trial version of the software which is available at Savannah's website [18].

Simwalk provides a SimDraw utility which is able to import AutoCAD designs, create and modify new environment designs. The software provides little difference between agents (movement delay and speed). As discussed earlier, pedestrians use static paths and therefore it can be used for simulating the movements inside the buildings. However, this software can not be used for movement like Tawaf.

Simwalk's underlying model is based on a social forces model. Movement trails, loads in each area, counters, flow information, level of service, speed and time to the destination of individual pedestrians, record and playback are some of the outputs of this software.

3 Evaluation Framework

We use an evaluation framework which is based on scoring method to determine the potential candidates. Based on our requirements, we have determined the maximum score for each category. The importance of each criterion is reflected from the weight being assigned to it. Table 1 lists the criteria and their initial weights while table 2 gives the details of the scores for each category. Simulation model has the highest score since we believe this will determine the accuracy and the reliability of the results. The ability to design and modify the geometry as the least because based on our survey many tools provide the import feature using existing popular design software (such as the AutoCAD) or at least provide some kind of drawing utility to meet this purpose. Large scale simulation is the second most important and the completeness of reporting and evaluation tools are deem necessary in helping the user assess the results of the simulation.

Evaluation Criteria	Weight
Capability of Simulating Large Crowds	25%
Geometry Design Tools	15%
Simulation Model (Movement Behavior)	35%
Reporting and Evaluation Tools	25%

Table 1: The maximum score of each criterion

3.1 Capability of Simulating Large Crowds

A 25% of the total score is considered for the ability of the software to simulate large crowds. Available systems are able to simulate a crowd with hundreds to several hundred thousands of pedestrians. This parameter is mainly related to the simulation model used in the software. Discrete models like cellular automata [10], [11] are fast and continuous models like social forces model [12] are more complex and therefore slower. As an example PedGo can simulate 50,000 to 100,000 pedestrians and MassiveSW, which is used for making animations can simulate more than a hundred thousand of pedestrians.

3.2 Geometry Design Tools

Environment design and modification capability is another important facility which will help us in our project. Most of the software systems allow us to design geometry, define stairs, entrances and exits, walkways and different objects on our map. Some of the software packages can simulate multi-floor architectures. Another useful capability which some of the packages provide is the ability to import geometry data from Autodesk ACAD format. A 15% of the total weight is considered for this section.

Capability of Simulating Large Crowds (25)	0.25 for each 1000 (23 for more than 90,000) Real-Time Simulation (2)
Geometry Design Tools (15)	Editor Capabilities (4) Import (ACAD,...) (6) Multi Floor, Levels, Stairs Design and Simulation (5)
Simulation Model (Movement Behavior) (35)	Model Type, Crowd Phenomena (15) : Continuous Models such as Social Forces etc. (10-15), Cellular Automata (7-12), Rule Based (3-7) Simulation of Individual Pedestrian Behaviors, High Level Agent Model, Difference of Agents, Easy Agent Creation (8) Macroscopic Model, Communication, Learning, Mental Map, Leader effects, Path Design Capabilities (6) Group Effects (3) Collision, Push, Fall, Trample and other (3)
Reporting and Evaluation Tools (25)	Reports for each or entire sections of the environment, such as entrance and exit counters, Flow details, throughput rates, density levels, congested areas, level of service, evacuation time (12) Reports about individual pedestrians, such as average delay, track and trail of the pedestrians, average and individual speeds, movement data for individual pedestrians, visualizing behaviors of individuals, average and individual evacuation times (8) Other useful outputs such as capture and playback, raw data, export to excel, ... (5)

Table 2: Detail features that contribute to the scores

3.3 Simulation Model

The validity of the simulation results is the most important parameter in the evaluation of the existing software. We have considered 35% of the total score for this section. A simulation software should be able to simulate different phenomena which exists in a crowd. Arch formation at doors, lane formation and oscillatory changes of the walking direction at narrow passages are among these phenomena. In order to provide accurate and useful results, the software should be able to simulate behaviors of individual pedestrians as well.

Some software systems are able to simulate the overall behavior of a crowd, for example, the details of the pedestrian flow while others are able to simulate the detail behaviors of individual pedestrians. One of the most important and effective parameters in simulation results is the model used for the microscopic local movements. Cellular automata model divides the space into discrete cells, which normally hold a single pedestrian. However, it cannot model pushing or falling behavior due to the constant size of the cells (for example 40 cm), pedestrians stand very orderly within the space and their speed can only be the multiply of the size of the cell in each time step. These models therefore are more suitable for simulating low to medium density crowds. Continuous models like social forces model are able to produce more precise results but as mentioned before they are relatively slow. Rule based models [13] can deliver realistic results in low density crowds. However, they are normally unable to simulate dense crowd specific phenomena [14]. A 15% of the total score is allocated to the microscopic model used in the software. Continuous forces models are more precise and therefore get a higher score.

In order to simulate dense crowds, a software model should be able to simulate behaviors specific to dense crowds such as pushing, collision, falling, trampling etc. The capability of simulating groups of people (members of a family, colleagues, etc.) is important because groups of people can act as an obstacle to other pedestrians. Furthermore, such phenomenon is very common in the Tawaf area. In addition to having a suitable microscopic model for local movements, a software should have a suitable macroscopic navigation and way finding model. These path design and navigation capabilities are useful to simulate special

movement patterns such as different pilgrimage actions such as Saie and Tawaf. Some models have features like mental maps for individual agents, learning and knowledge transfer between agents.

3.4 Reporting and Evaluation Tools

Sufficient reporting tools are necessary for a successful evaluation. A software may only provide visual output of the movements while others may provide extensive reports. Flow details, entrance and exit counters, throughput rates, density levels, congestion areas, level of service, average delay, track and trail of the pedestrians, evacuation time, average speed, movie captures are among these useful reports. Without these reporting tools, the software can be hardly useful. We have considered a 25% weight for reporting capabilities.

4 Evaluation Results

After investigation of the available documents and testing available demos, we have reached the results for seven selected software packages (see table 3). We tested the demo software provided by Simulex, STEPS and Simwalk but the other four software are evaluated using data gathered from software documents, brochures, case studies and papers. The results of the evaluations determine which software can potentially be more capable of simulating a dense crowd such as the Masjid Al-Haram.

		Capability of Simulating Large Crowds (25)	Geometry Design Tools (15)	Simulation Model (35)	Reporting and Evaluation Tools (25)	Total (100)
Evacuation Only	Aseri	3.45 (13.8%)	14 (93.3%)	16.5 (47.1%)	6.2 (24.8%)	40.1
	PedGo	11.5 (46%)	7.8 (52%)	9.3 (26.7%)	6.8 (27.2%)	35.4
	Simulex	2.9 (11.6%)	14.4 (96%)	10.6 (30.4%)	4.9 (19.6%)	32.8
	GridFlow	2.3 (9.2%)	6.7 (44.6%)	8.25 (23.5%)	6 (24%)	23.2
Normal and Evacuation	Legion	3.4 (13.8%)	14.2 (94.6%)	19 (54.4%)	13.6 (54.4%)	50.3
	Steps	6.6 (26.4%)	12.4 (82.6%)	15 (42.8%)	13.1 (52.4%)	47.1
	SimWalk	4.3 (17.2%)	10.9 (72.6%)	14.1 (40.4%)	11.4 (45.6%)	40.7

Table 3: The raw score and the corresponding percentage of each of the software

For the purpose of simulating the crowd in Masjid Al-Haram we require software that is able to simulate the normal situations apart from the evacuation study. Simulex, PedGo, Aseri and Gridflow are intended for evacuations only while Legion, Steps and SimWalk, are able to simulate both evacuation and normal situations.

For the first category (simulating the large crowd) PedGo outstand the rest since it is able to simulate large crowds. PedGo gets lesser score for the geometry design because, as described earlier, the AutoCAD import feature is not ready in the investigated version. As for the simulation model category Legion comes with extensive features compared to the others and hence obtains higher score. Legion, STEPs and SimWalk provide more "report and result evaluation tools" and therefore obtain better scores in this category.

Our initial candidates for the next level of evaluation are SimWalk, Legion and Steps for mitigation studies. All three software are able to simulate both evacuation and normal situations. If we were going to obtain a product which is only able to simulate evacuation process we would suggest Aseri and PedGo. However, obtaining one of the software which is able to simulate both situations would be better able to fulfill our requirements since it is more economical.

5 Simulation using STEPs

During the study we were able to work with the demo versions of STEPs, Simwalk and Simulex. Among these software STEPs proved to have more extensive features. Building a simulation model in STEPs would involve defining different pedestrian types, pedestrian groups, creating floors and objects, specifying doors and exits, defining events and running the simulation. Alternatively we might import an AutoCAD file and build the model using the imported plan. Tutorial and example projects which come along with the software show extensive features of STEPs to simulate complex structures (figure 1). The software also proved to be able to simulate a model with more than 20,000 pedestrians on a single PC. As mentioned earlier the software is able to simulate both emergency situations and normal studies. The effect of gas, smoke and fire can be considered in the evacuation mode. We believe the software will enable us to suggest crowd control for both evacuation and normal movements of the people for some parts of Masjid Al-Haram. The only concern would be the excessive number of pedestrians in some areas of the mosque. We will need to use a powerful computer (e.g. multiprocessor machines) to run the simulation in these cases.

Figure 1: Simulation of a stadium using STEPs

6 Price

We have been able to gather an estimate of the costs of the mentioned software either from company websites or through communication with the companies. Our first candidate namely Legion proved to be very expensive (more than £20,000 for a one year license) while STEPs is reasonably lower (a few thousand pounds for a 1 year license). Simwalk according to the product website costs £2200 for a permanent license for corporate use and £1050 for educational use. As a result the choice of Legion will depend on the budget assigned to the project while obtaining STEPs and Simwalk is perhaps possible within a limited budget.

7 Conclusion and Future Work

During the study we encountered some limitations of the existing software. For example, accurate simulation of Tawaf area is hardly possible and the formation of "saf" is difficult to model. In our opinion building specific simulation software for Masjid Al-Haram is the only alternative. Such a software should incorporate the four important criteria that we have highlighted earlier, namely, large scale simulation,

simulation models which could produce realistic and accurate results, useful and comprehensive reporting tools and the ability to design and modify the geometry. Our future work includes detail assessment of the existing simulation methods and the design of the simulation system which meets the requirement of the simulation of the crowd at the Masjid Al-Haram.

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