Software Evaluation for Crowd Evacuation – Case Study: Al-Masjid An-Nabawi

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Abstract

Disaster preparation and management, such as emergency evacuation, is very essential for public places. This is especially true for Al-Masjid An-Nabawi which accommodates millions of Muslims around the world during Umrah and Hajj seasons. This paper describes the evaluation process carried out to determine the most suitable software for the purpose of studying the evacuation process of Al-Masjid An-Nabawi. This process starts by identifying the project requirements such as the scope and nature of the project, information and data available (e.g. floor-plan, total occupancy of the mosque), duration of the project and the budget. This is then followed by the survey on all available crowd simulation software. Assessments were carried out in terms of degree of validation, background nature of the software, the models used and features available. These were among the main criteria used in short-listing the potential software to be purchased. Observations and identifications on congestion-prone areas, as case studies, were also performed.

Keywords: *Crowd simulation software, Hajj, Al-Masjid An-Nabawi, evacuation.*

1. Introduction

The evacuation of people from crowded areas is a process that could involve risking the lives of people especially during emergency situations. Therefore, planning for an unexpected emergency situation is the key to people's safety. There have been many incidents of crowd disasters in many areas around the world: in sporting events, religious gatherings, night clubs, shopping malls, festivals, schools, business offices and high-rise buildings [1][2]. For example, in New York City, Bronx, in 1990, at the illegal Happy Land Social Club, 87 people died [2]; in 2001 at Ellis Park Stadium in Johannesburg, South Africa, a stampede resulted in the death of 43 people [4]; in 1999, a fire stampede in a shopping mall in South Korea resulted in the death of 54 people and injuring 71 [2]; in 2010 more than 349 people perished in a bridge stampede during a water festival in Cambodia [3]. Many crowd disasters have been reported during Hajj seasons in Saudi Arabia; the revolt in the Holy Mosque (Al-Masjid Al-Haram) in Makkah, in 1979, which resulted in the death of 250 people, and the Jamarat Bridge stampede incidents during the Satan stoning rituals which killed over 250 people in 2004 and a similar incident in 2006 resulted in the death of 300 people [1][2][3][4].

As mentioned above, houses of worship are no different from other public places, which could accommodate hundreds of thousands or even millions of people at one time. Al-Masjid An-Nabawi in Madinah, Saudi Arabia, is one example. The mosque (Masjid) could accommodate up to one million people during Hajj season. Hence, disaster preparation for such a place is of utmost important. The objective of this work is to evaluate the suitable crowd simulation software for evacuation purposes of Al-Masjid Al-Nabawi. The software will later be used to estimate the overall evacuation time, identify congested areas and also for corrective actions related to emergency planning.

In view of the importance of the place, the Crowd Research Team at Taibah University has made an effort to contribute to the safety of the pilgrims through a project entitled, "Towards More Efficient Evacuation Process at the Grand Mosque of Prophet Mohammed". The project is divided into two phases; Phase I - Software evaluation and identification of the crowd prone areas. Phase II - Simulation experiments and comparative evaluations. This paper describes our findings of the first phase of the project.

This paper is organized as follows: section 2 provides the related work, section 3 presents the methodology used in evaluating the project requirements, section 4 discusses the results and recommendations and finally the paper concludes with section 5.

2. Related Work

Evacuation Modeling Portal [5] is one of the popular resources on the subject of evacuation. Hence, the portal has been the main reference and a starting point of this project. At the time of the writing of this paper, there were 5 articles [6-10] available at the portal, and also a table of 55 evacuation software listed in the Evacuation Model Summary Table.

The paper by Kuligowski and Gwyne [6] provided useful guidelines in assessing the general requirements of crowd modeling and simulation projects. It also shed some lights on the importance of the background knowledge of evacuation software. The authors also listed several software features to be used as evaluation criteria. Hence, we used the paper in assessing the requirements of this project. In [7], Kuligowski et al. provided a detail review of the main and special features of evacuation software. Example main features are availability, modeling method, purpose, model grid or structure, the perspective of the occupant, how the model views the entity, behavioral and movement model, fire effects, CAD drawing support, visualization and validation methods. Special features referred to software specific capabilities, for example, counter flow, groups, route choice, obstacles at exits, and others. Castle [8] also provided similar review, however, in our opinion, [7] is more comprehensive. Santos and Aguirre [9] presented a review of simulation models such as flow-based, cellular automata, agent-based and activity-based alongside three software which incorporated social aspects of occupants. However, no simulation comparison carried out on the software. Lord et. al. [10] reported a 3-year study in determining significant parameters that determine the simulation results. They based their study on STEPS and EXIT89 simulation software. However, the results were not conclusive enough. Ronchi and Kinsey [11] presented their online survey. The authors have some reservation since there exist some elements of bias in the survey. Some of the software developers made the initiative to encourage their users to participate in the survey as compared to others. The results may favor them due to the efforts. A relatively recent and useful coverage on crowd modeling and simulation can be found in [12] which provide almost all aspect of crowd study, starting from the fundamental graph of speed-density to the application of evacuation software.

3. Methodology

This section describes the method that was used in the evaluation. Kuligowski and Gwynne [6] recommended the users to look into four different factors which determine the selection of the suitable software; they are (i) project requirements, (ii) background information, (iii) software model characteristics and (iv) future considerations. In the following sections, the first three factors are investigated in the context of this project and a brief mention on the fourth is included at the end.

3.1 Project Requirements

Kuligowski and Gwynne suggested the users to consider the following four points as a guide in the selection of the appropriate software.

1. The nature and scope of the project – whether it is for offices, malls, high-rise building, airport terminals, train stations, stadium, maritime, airplane etc. The Masjid An-Nabawi is a place of worship visited by millions of Muslims from over 100 different countries with high percentage of elderly. Structurally, the mosque is a two-floor rectangular shape building, mostly carpeted, with many pillars and doors. Distinct sections separate the female from the male. However, no work or case study has been found in the literature which is similar to this work.
2. The deliverables of the project are:
   (i) A review of existing software, criteria for the chosen and the short-listed software.
   (ii) An analysis on the simulation scenarios in terms of required evacuation time and degree of accuracy.
   (iii) A comparison in (ii) using at least two different software.
3. Information available, especially those that are needed for the simulation experiments.
   - Floor plan of the mosque including details such as placement of obstacles (e.g. Zam-zam containers and Quran shelves) and dividers (e.g. women without children section from the rest).
   - Detail statistics of visitors - male/female, age, nationalities, disable (e.g. wheelchair users) – all these are needed for the entity profiles.
   - Information on trial evacuation (if any), this is very essential to ascertain the accuracy of the predicted evacuation time.
   - Movement speed of pilgrims (which can be extracted from top-view video). We need the support from the authorities of the mosque.
4. Duration and funding of the project, in this case, is a 1-year project with a small budget which constraints the choice of the software to be purchased. The

duration also limits the scenarios that we can actually study.

3.2 Background Research of the Software

A good understanding on the origin of the model helps user to have some idea on the credibility and reliability of the software. There are three factors to be considered:

- Constraint under which the software was developed – funding or time or the needs to improve. It is difficult to get this information, other than through the direct interactions with those in this area.
- Expertise involved in the development of the software – whether it is a PhD product (e.g., Simulex and PedGo), a team with different expertise such as mathematicians, psychologist etc.
- Validation and verification – the extent of the validation determine the confidence on the software. There are four different validation types specified in the Evacuation Model Summary Table;
  (1) Validated against fire drill or people movements experiments
  (2) Validated against literature
  (3) Validated against other model
  (4) Third party validation.

The software have been grouped as follow, according to the level of validation:

(i) Very extensive - Evi, Exodus and Legion have been validated against all of the above types.
(ii) Extensive - Simulex and SimWalk (1,2,4), FDS+EVAC (1,2,3), Pathfinder (1,2,3). The numbers refer to validation types, above.
(iii) Less extensive – ASERI (validation type 1, 2), EPT (1), EVACNET4/EVACNET+ (1), MASSEgress (2,3), PEDFLOW (2), STEPS (1,2), VISSIM/VISWALK (2). It is to be noted that EVACNET4/EVACNET+, MASSEgress and PEDFLOW are publicly available while STEPS can be used for free for the purpose of this project.

Preferences go to those which have gone through very extensive validation such as Evi, Exodus and Legion, followed by those that are one level below that is Simulex, Simwalk, FDS+EVAC and Pathfinder.

3.3 Model Characteristics

In this section, we provide the comparison between software in relation to the specific requirements of the project. Prior to that, the original list of software was first filtered.

3.3.1 Short Listing of the Software

The Evacuation Model Summary Table is a listing of 55 software, with each having 25 columns of general information and model features. The first step was to filter the software with incomplete information (columns that were not filled) and those which were not included in NIST (National Institute of Standards and Technology) review. A total of 28 software were removed from the original list. They are as follow:

AENEAS, BTS (Building Traffic Simulator), BUMMPEE, Cube Avenue, DBES (The Distributed Building Evacuation Simulator), E-Scape, EEscape (Emergency Escape), ELEVATE, ELVAC, ESM, EVACSIM, EXITT, F.A.S.T.(Floor-field and Agent-based Simulation Tool), FIRECAM, FIRETECH, Flowtech, Helios, Lisi, Magnetic Model, MASCM (Multi-agent Simulation for Crisis Management), MASSIVE Software, Micro Saint, Nomad, PedSim, SimPed, SMART Move, TSEA: Transient Simplified Egress Analysis, ZET.

The remaining list was then divided into three main categories, based on their availability:

(i) Not available
  a. Consultancy use only (5) - ALLSAFE, CRISP, EGRESS, EvacuationNZ, SGEM
  b. Publicly available and consultation basis (5) – Gridflow, Mass Motion, Myriad II, Paxport/PedRoute, PedGo
  c. Not publicly available (1) – EXIT89

(ii) Publicly or freely available (6) – EVACNET4/EVACNET+, FDS+Evac (Fire Dynamics Simulator with Evacuation), MASSEgress, PEDFLOW, SpaceSensor and STEPS. STEPS is included here since it is available for free.
(iii) Available but require access fees (10) – ASERI, EPT (Evacuation Planning Tool), Evi, EXODUS, Legion, PathFinder, SIMULEX, SimWalk, VISSIM/VISWALK, Wayout.

Those that are accessible are under category (ii) and (iii). Therefore, in total there are 16 software that could be the candidates of this study, out of which six are freely available and ten require close evaluation for purchase. It is to be noted that the seven software in the online survey [10] falls under this 16.

The above 16 candidates were then matched with the findings in section 3.2 on the level of validation. The final list is reduced to the following; Exodus, Legion, Simwalk, FDS+EVAC and STEPS (since it is free although it falls under the least validated). The company that provided Simulex has evolved to providing other services, while with Evi, no sufficient information could be found on the software (at the time of writing of the paper).

3.3.2 Evaluation of the Main and Special Features of the Software

The final list of software was then evaluated; Exodus, Legion, Simwalk, FDS+EVAC and STEPS, based on the features discussed in [7]. The evaluation took into account the specific requirements of the Masjid An-Nabawi (and also Masjid Al-Haram, for future projects). Tables 1 and 2 provide the evaluation results for both, the main and special features, respectively. The second column in both tables shows the specific requirements of the mosque. Note that, Myriad II was included as a benchmark, since it was used extensively by Keith Still for many big events including the Jamarat Bridge [13].
We are interested in the following features since they have a major influence on the evacuation time:

1. Grid/structure and movements – this concern with the modeling of the space and the physical movements of a person. Coarse network for example model movements from one space/location to another, e.g. room to stairs. Fine grid divides the space into cells and individual moves to the next cell if it is empty. Continuous on the other hand make use of forces (or potential) to determine the next point of locations of a person. Some incorporate the 360 degree (a circle) surrounding a person as the minimum inter-person distance. Continuous seems to have smoother movements as compared to cell-based, therefore, as long as the emerging or resulting behaviors are similar – then it does not really matter. More important, both models must be able to simulate the effects of obstacles and barriers.

2. Behavioral vs partial-behavioral – in general human movements are not limited to physical only. As human move they think and decide on the different actions. So, behavioral would be more appealing especially those that are Artificial Intelligence-based.

It is to be noted that the Evacuation Model Summary Table (mentioned in Section 2), is based on the information provided either by NIST (derived from the literature) or developers themselves (which could reflect the software more closely or it can also be just claims). The results from the actual simulations should be the main criteria.
Another aspect is on the output (there are common metrics and also specific to individual software):

- Example metrics which are related to the "physical" aspect of the crowd are evacuation time, walking time, density map and level of service, space utilization map, throughput map, critical time, total count passing the exits.
- Example behavioral features are inconvenience, discomfort, frustration (which are all quantified).

Given time, the plan is to also use the software to simulate selected sections of the Masjid Al-Haram in Makkah, the first holy site of the Muslims. Hence, we included the special requirements of the place as well, as shown in Table 2.

4. Results and Recommendations

The following are the (partial) results based on the assessments that were carried out and also financial constraint of the project.

1. A decision was reached to purchase and use the following software for the project:
   (i) BuildingEXODUS – which is a specialized software for evacuation study.
   (ii) Simwalk – whose strength is in the human-like movement model and also for future work on non-emergency situations.
   (iii) A freely available software such as STEPS and/or FDS+Evac, will be used as comparison.

   It is to be noted that, this does not imply the chosen software are more superior. As mentioned above, the financial constraint is one of the influential factors. The final decision will very much depend on the experience gain from the simulation experiments.

2. As for the specific simulation case studies, the mosque will be divided into 7 different areas or sections (Fig. 1). This will result in 6 different simulation scenarios, as follow:
   (i) The two ladies sections (marked as 1 in Fig. 1) of the mosque are not symmetrical and two simulations should be performed.
   (ii) Sections number 2 (Fig. 1) are symmetrical and one simulation could be performed.
   (iii) The other two sections are the old mosque section and the central umbrella areas (number 3 and 4 in Fig. 1).
   (iv) Finally, the section between the ladies' sections with exit at King Fahd door (number 5 in Fig. 1).

Table 1: Evaluation of Main Features of Crowd Software

Main features	Our Requirements	Exodus	Legion	SimWalk	FDS+EVAC	STEPS	Myriad II
Availability	**Free** or access **fee**	Access fee	Access fee	Access fee	Free	Free	-
Modeling method	**Behavioral** is more suitable-we may need for decision-making to simulate specific conditions.	Behavioral	Behavioral	Partial behavioral	Partial behavioral	Behavioral	Behavioral
Purpose	Able to simulate any type of building-can use **any** of software.	√	√	√	√	√	√
Grid/structure	Fine network may have limitations like the cell-based. Continuous produces a fine movement since it does not define any structure to the space. However, both fine and continuous are able to model obstacles and barriers. It is good to look into **both** models.	Fine network	Continuous	Continuous	Continuous	Fine network	Fine network Continuous Coarse network
Perspective of the Model on Occupant	Detail on individual is known, which allow tracking-can use **any** of software	Individual	Individual	Individual	Individual	Individual	Individual
Perspective of Occupant on Building	Individual means occupant does not have global knowledge of all exits in the building-**any** software	Individual	Individual	Individual	Individual	Individual	Individual
Behavior	Most software use "if-then" conditional behavior with some probability distributed among occupants. If we can have AI-based that is more of human thinking, woud be good. Minimally, **conditional, probabilistic**.	Conditional (or rule) behavior Probabilistic	Artificial Intelligence Probabilistic	Conditional (or rule) behavior Probabilistic	Conditional (or rule) behavior Probabilistic	Conditional (or rule) behavior Probabilistic	Artificial Intelligence
Movement	Potential+grid cell refers to weighted that will direct the movement of the individual. Inter-person has to exist with force-based or potential model to limit the distance between people. Conditional is like guiding behavior of movement or traversing rather than individual steps. It is good to evaluate these **two approaches**.	Potential Emptiness of next grid cell	Inter-person distance Conditional	Potential	Inter-person distance	Potential Emptiness of next grid cell	Density correlation, Inter-person distance, User's choice, Acquiring knowledge
Fire effects	We can start with non-fire then move to **fire** scenarios since most support fire.	Import fire data/results from another model Allowing the user to input specific fire data at certain times throughout evacuation.	Import fire data/results from another model	Cannot incorporate fire data, it simply runs all simulations in "drill" or non-fire mode.	Have own fire model that can be run simultaneously with the evacuation model, however, the evacuation model can also be run in "drill" mode.	Import fire data/results from another model. Allowing the user to input specific fire data at certain times throughout evacuation	Import fire data/results from another model
CAD drawing	Allow import of CAD	√	√	√	√	√	√
Visualization	• 2-d visualization or • 3-d visualization	√ √	√ √	√ √	√ √	√ √	√ √
Validation	• Validation against fire drill or other's experiments/trials • Validation against literature on past experiments • Validation against other models • Third party validation (bonus)	√ √ √ √	√ √ - √	√ √ - √	√ √ √ -	√ √ - -	- √ - √

Table 2: Evaluation of Special Features of Crowd Software

Special features	Our Requirement	Exodus	Legion	SimWalk	FDS+EVAC	STEPS	Myriad II
Counter-flow	Counter-flow is typical scenarios especially at doors	Yes	Yes	Yes	Yes	Yes	Yes
Delays/pre-evacuation times	This is more realistic to include as people do not evacuate immediately	Yes	Yes	Yes	Yes	Yes	Yes
Disability/slow occupant groups	We need this, many pilgrims are old and some wheel-chaired.	Yes	Yes	Yes	Yes	Yes	Yes
Exit block/obstacles	Wheelchairs block the doors (prominent at Masjid al-Haram)	Yes	Yes	No	Yes	Yes	Yes
Fire condition affect behavior	Good to have if we simulate fire.	Yes	Yes	No	Yes	Yes	Yes
Defining groups	One of the characteristics of pilgrims especially at Masjid al-Haram	Yes	Yes	Yes	No	Yes	Yes
Elevator use	We need especially for Masjid Al-Haram.	No	Yes	Yes	No	Yes	Yes
Route choice of occupants	Conditional, user-define and shortest/optimal route are useful.	User-define Conditional	Conditional	Shortest-route	Optimal Conditional	Conditional	Various

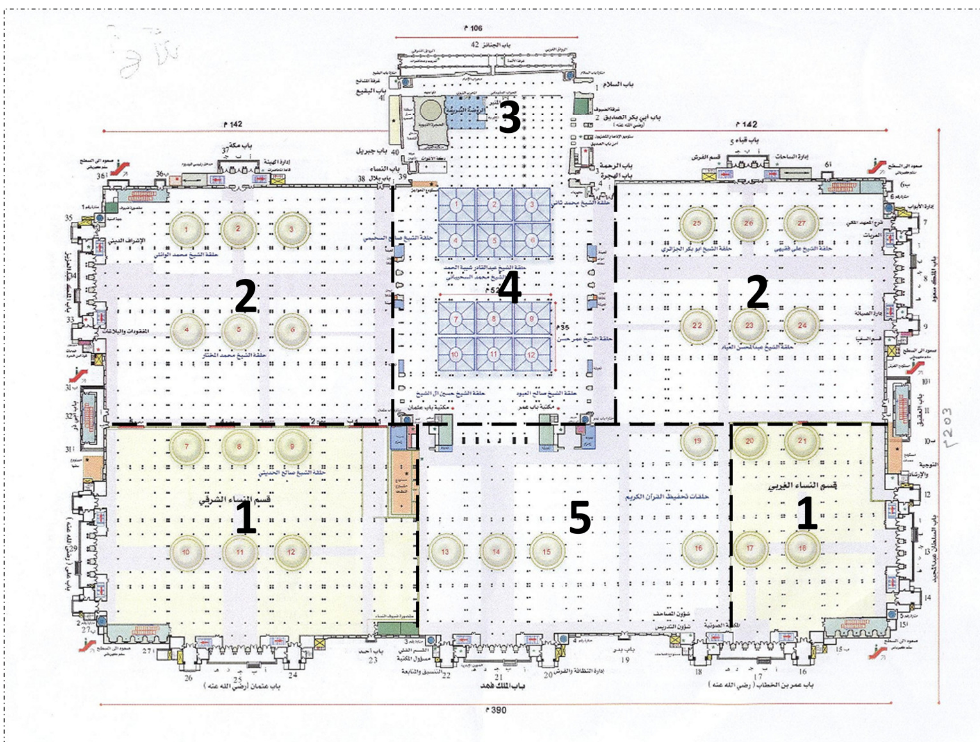

Fig. 1: Division of simulation areas of Masjid An-Nabawi

5. Conclusion and Future Work

The detail results of software evaluation of the main and special features of crowd software are shown in Tables 1 and 2. From this evaluation, it has been concluded that the most suitable software to be investigated for the simulation of crowd evacuation at Al-Masjid An-Nabawi are: BuildingEXODUS and SimWalk. In addition, Legion is also suitable; however, due to its high cost it was eliminated, given the limited funding of the project. The STEPS and FDS+EVAC, are free access software, which are also recommended for this case study and time permitting their results will be used to compare to those obtained from BuildingEXODUS and SimWalk.

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