A GIS-BASED SPATIAL-TEMPORAL VISUALIZATION OF PEDESTRIAN GROUPS MOVEMENT TO AND FROM JAMART AREA

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Abstract: The movement of pedestrians in Mina (near the city of Makkah, Saudi Arabia) during the Hajj an Islamic Pilgrimage is a major concern for urban planners and designers for a number of reasons. The "Stoning the devil" ceremony in Mina's Jamarat area during the ceremony of the Hajj is performed by more than three million Muslims every year. The pilgrims "Stone the Devil" by throwing seven stones at each of three Jamarah (stone pillars). As the number of pilgrims increase, the Jamarat area witnesses overcrowding problems every year. In recent years, the crowd has panicked and pilgrims were trampled to death, also Managing the pedestrian traffic in urban environments is an important way to prevent these types of tragedies created by overcrowding. A way to help curb the problem of overcrowding could be accomplished by designing the more robust urban environment, and better managing the movement within the urban environment. This paper discusses a spatial-temporal visualization of the movement of pilgrim groups to and from Jamarat area according to a schedule developed by the Ministry of Hajj. The approach utilizes GIS (Geographic Information Systems) to simulate the movement of groups of pilgrims from their tent camps to Jamarat and back to their camp. Using the API of GIS, a code has been developed to generate series of points with time stamps that represent and track the movement of each subgroup of pilgrims. This is done based on a shortest path algorithm. These track points are then loaded into a tracking analysis extension of the GIS software. A spatial-temporal visualization of pedestrian movements to and from Jamarat area is then played. The software can also visualize critical overcrowded areas at different times over the three days of the ceremony. In this research it is customized to visualize overcrowding at the Jamarat area. This provides a useful tool to when evaluating the developed time schedule for group movements. It could be used to evaluate the design and planning of the urban environment. The paper concludes with possible applications of the approach developed through this research. Some ways of making this approach is to be more reliable, validated, and realistic which are also discussed in this paper. Future approaches to designing a fully automated system that generate a movement time schedule are also proposed.

Keywords: Pedestrian Movement Visualization, GIS, Jamarat

1 INTRODUCTION

The movement of pedestrians in Mina's built environment during Hajj is a major concern for urban designers and planners for many reasons. Hajj is the Muslims' pilgrimage to Makkah and the Holy Places. It is one of the most important events in world that occurs annually and attracts more than two million people from all over the globe. According to Islamic literatures, Hajj represents following prophet Abraham's legacy who rebuilt the first House of God, the Ka'ba located in the centre of the Holy Mosque, Makkah.

Mina (Figure 1) is an area located near the city of Makkah, Saudi Arabia. Mina is located at a distance of 6 km from Central Makkah, and measures approximately 812 hectares, 52% of which is flat land. The hilly part is comprised of very steep slopes, very difficult to use by most pilgrims. Part of the Hajj rituals is to stay in Mina for two or three nights. Mina is mainly constructed of tent camps to accommodate the huge number of pilgrims and the traffic to facilitate movement of vehicles and pedestrians. Pilgrims are divided into groups and distributed into different tent camps in Mina.

During the stay in Mina, pilgrims have to go to the Jamarat area in Mina to throw the pebbles. Throwing Jamarat (stone pillars) is part of the pilgrimage process. According to Islamic literature, Jamarat are the shrines marking the places where the prophet Abraham stoned Satan for trying to persuade him to disobey one of God's commands. The "Stoning the devil" ceremony in Mina's Jamarat area during the Hajj period is performed by more than three million Muslims every year. The pilgrims "Stone the Devil" by throwing seven stones at each of three Jamarat (Jamarat Al-Soghra, Jamarat Al-Wosta, and Jamarat Al-Aqabah). During the pilgrims stay in Jamarat, they go every day to throw Jamarat from their tent camps. After throwing Jamart they either return to their camps or go to some other places in Makkah, such as the Holy Mosque (Al-Haboubi, 2003 and Al-Zahrani, 1989).

Figure 1: The Holy area of Mina near Makkah
Courtesy: Hajj Research Institute

In recent years, the Jamarat area has witnessed many serious accidents due to overcrowding at the Jamarat area. Problems of overcrowding in the Jamarat area have led to the construction of a gigantic pedestrian bridge (fly-over) in that area many years ago (Ghandoorah, 1988). This has made it possible for pilgrims to throw Jamarat at two levels, above and below the bridge (Figure 2). Despite the construction of the bridge, with the increasing number of pilgrims the overcrowding (Figure 3) problems still remain.

Figure 2: Jamarat bridge in Mina
Courtesy: Hajj Research Institute

Figure 3: Overcrowdings in Jamarat area
Courtesy: Hajj Research Institute

Overcrowding peak times in the Jamarat area are: 1) From the sun rise till midday on the 10th day; 2) Noon and after noon on the 11th day; 3) Noon time on the 12th the day of Thul Hijja. In recent years, the crowd has panicked and pilgrims were trampled to death. Table 1 shows the locations of accidents and number of deaths that occurs during the recent years.

Location of accidents	Year	Number of Deaths
North east of small Jamrah	1994 (1414H)	270
North east corner of the eastern entrance ramp	1997 (1417H)	24
North east corner of the eastern entrance ramp from inside out to the outer yard	1998 (1418H)	118
North of Aqabah Jamrah	2001 (1421H)	35
North of Aqabah Jamrah	2004 (1424H)	251

Table 1: Jamarat accidents in the last 10 years

Several solutions are proposed to resolve the overcrowding problems in the Jamarat area. Barhamin and Muhrez proposed to reduce the high density periods through scheduling of arrivals (Barhamin and Muhrez, 1989). This approach seems reasonable but requires a scientific study and enforcement. Al-Gadhi noted that the density of people around the target should be encouraged to be uniform (Al-Gadhi 1990). This suggestion requires directing the attention of pilgrims to lower density spots.

Managing the pedestrian movement in Mina's built environments is an important way to prevent the tragedies created by overcrowding. Local authorities have attempted to utilize IT (Information Technology) to support crowd control and management in the Jamarat area. Most of these efforts, however, have failed to address the spatial dimension of movement scheduling. This research discusses a spatial-temporal visualization of the movement of pilgrim groups to and from Jamarat areas according a schedule of movement developed by the Ministry of Hajj. The schedule (see sample in Figure 4) is generated based on a RDBMS (Relational Database Management System), Oracle. The system captures each group of attribute data (such as the number of pilgrims). It doesn't capture the exact location via a digital map of tent camps and the path of movement. The location is specified by a code for each block in Mina. The schedule takes the spatial representation of the pilgrims movement. In the approach developed through this research work, the spatial component is integrated with the database via utilizing GIS (Geographic Information Systems).

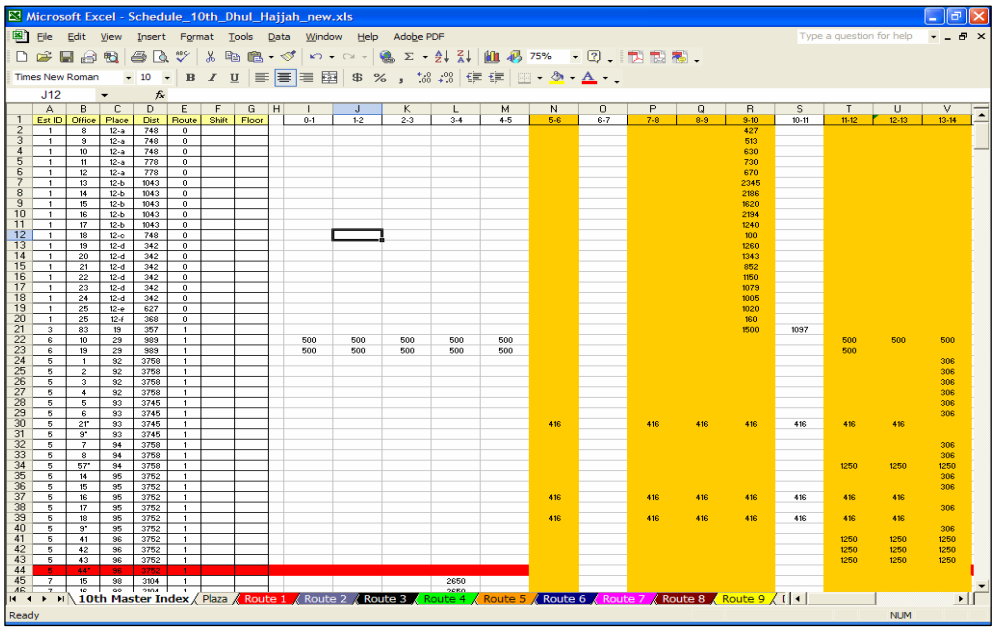

Figure 4: Sample schedule of movement generated by the Ministry of Hajj

Most of the simulation approaches that have been implemented in relation to the Jamarat overcrowding problems focuses on the Jamarat area or bridge. While the overcrowding problems occur at the Jamarat area, this overcrowding is also caused by macro factors. These simulation approaches focuses on the micro level not the macro level. The micro level here means the Jamarat bridge area. The macro level is the Mina's built environment that effects the flow of pilgrims movement to the Jamarat area. This research work focuses on the macro level of the problem.

2 APPROACH

In this research, GIS is utilized to integrate the spatial component of pedestrian movement to and from the Jamarat area. GIS offers the ability to add the location information to other attribute data of each group of pilgrims. The following explains the steps of the approach to reach the gaols of this research.

2.1 Building a GIS

First, a base map representing different features of Mina's built environment is created. The first layer is created to represent the different features of the traffic network as shown in Figure 5. The traffic network layer represents the

paths of pedestrian movement to the Jamarat area. Another important layer (Figure 6) represents blocks of Mina area. Each block includes a group of tents camps. Finally, the Jamarat bridge is represented in another layer. This Jamarat layer represents the target point for pedestrians coming from their tent camps.

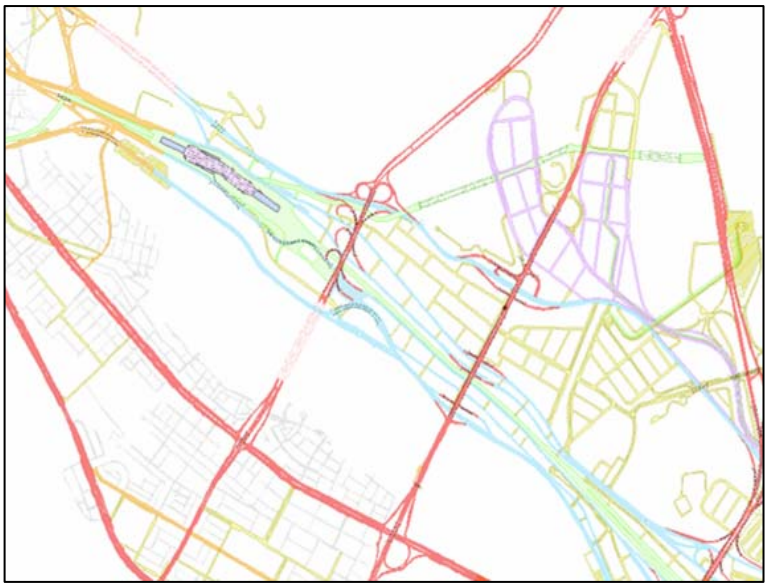

Figure 5: A layer represents the traffic network in Mina

Figure 6: A layer represents the blocks in Mina

Each tent camp is surrounded by a fence to separate them. The boundary of each camp is represented by a polygon in a different layer. Each camp represents the start of movement to the Jamarat bridge. The source of pedestrian movement to Jamarat area is represented as the gates of each camp. A layer representing each camp gate was created to capture the gate location and all related attribute data. These data include: the number of pilgrims in each camp, the name of establishment, and the group number. Each group of pilgrims belong to a an establishment. The representation of camp boundaries and camp gates are shown in Figure 7.

Figure 7: Representing Tent Camps and Gates

Another important representation to be captured in this research is the logical movement network. This is represent by two layers shown as junctions (nodes) and edges (links). Junctions represent the road intersections and camp gates. The edges represent the road that connects to intersections. This representation is essential to run shortest path algorithms. This research is based on the assumption that the pilgrim group should take the shortest path from the tent gate to the Jamarat area. The representation of the logical movement of pedestrian as junctions and edges are shown in Figure 8.

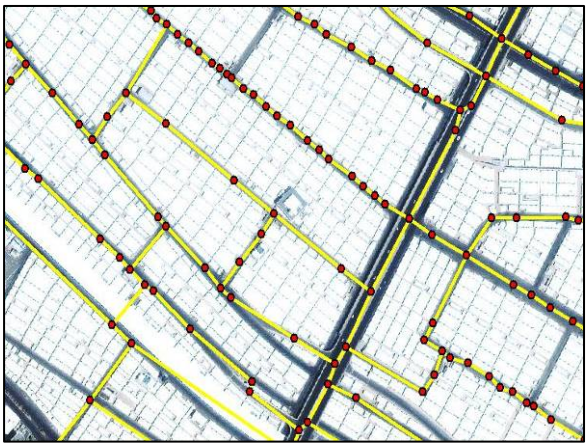

Figure 8: Representing traffic network as junctions and edges

Once the logical network movement is represented as junctions and edges, shortest path algorithms can be implemented. In this research, the shortest path algorithm is utilized to generate the expected tracks of pedestrian movement. Figure 9 is shows the results of running the shortest path algorithm between two junctions. Two kinds of major movements are happening in Mina. The first kind of movement is toward the Jamarat bridge. In this scenario the source of movement starts from the gates of tent camps and ends at the Jamarat area. The second kind of movement is outward of the Jamarat bridge. In this movement the pedestrians move from the Jamarat bridge back to their tent camps. In this research both movements are captured.

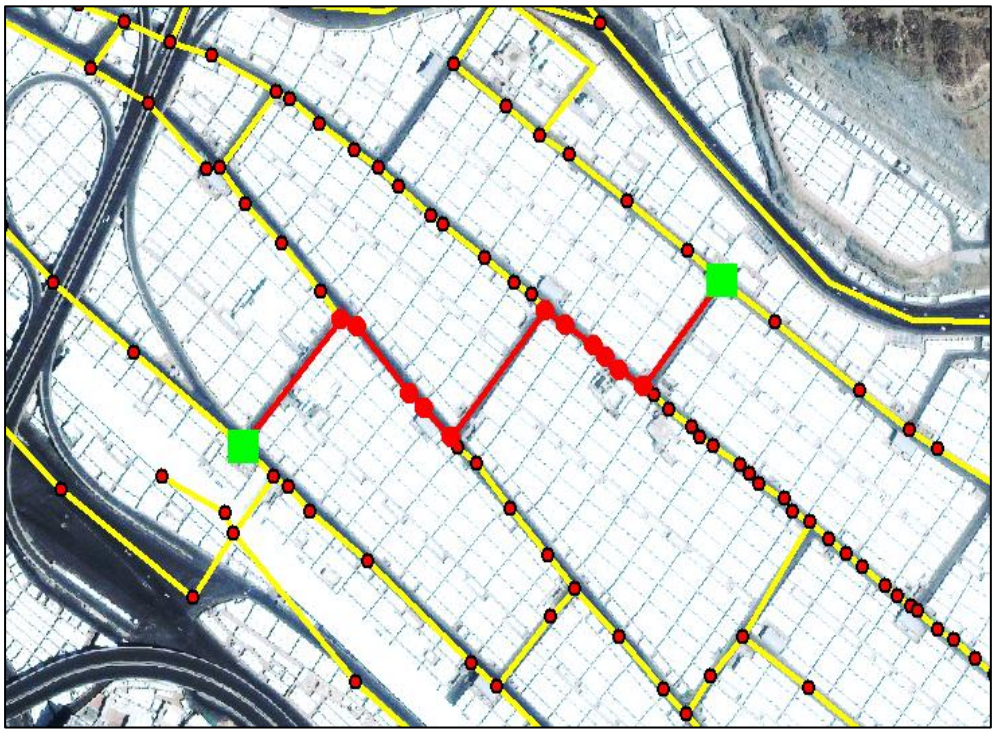

Figure 9: Result of running a shortest path algorithm between two junctions

2.2 Prototype Implementation

To generate the expected tracks of movements of each group of pilgrims a script has been developed using Visual Basic for Application (VBA) with ArcObjects. ArcObjects offers reusable GIS objects that can be utilized to build custom applications. This script generates the shortest path of pedestrians from their tent camps to the Jamarat area. In this research the shortest path is based on distance only. This path forms the track of pedestrian movement. Each track is then divided into equal distance points with expected time stamps. The script takes the schedule of movement

generated by the RDBMS as an input. For each camp the start time of pilgrim movement is taken from this schedule. Then, for each track point the time is incremented according to an estimated speed of pedestrians in Mina's built environment. The script generates the movement track points from the tent camps to the Jamarat area and the track points from the Jamarat area to the tent camps. These track points with time stamps are stored in a feature class in a geodatabase. Figure 10 shows samples of these track points for three groups of pilgrims going to the Jamarat bridge coming from different locations.

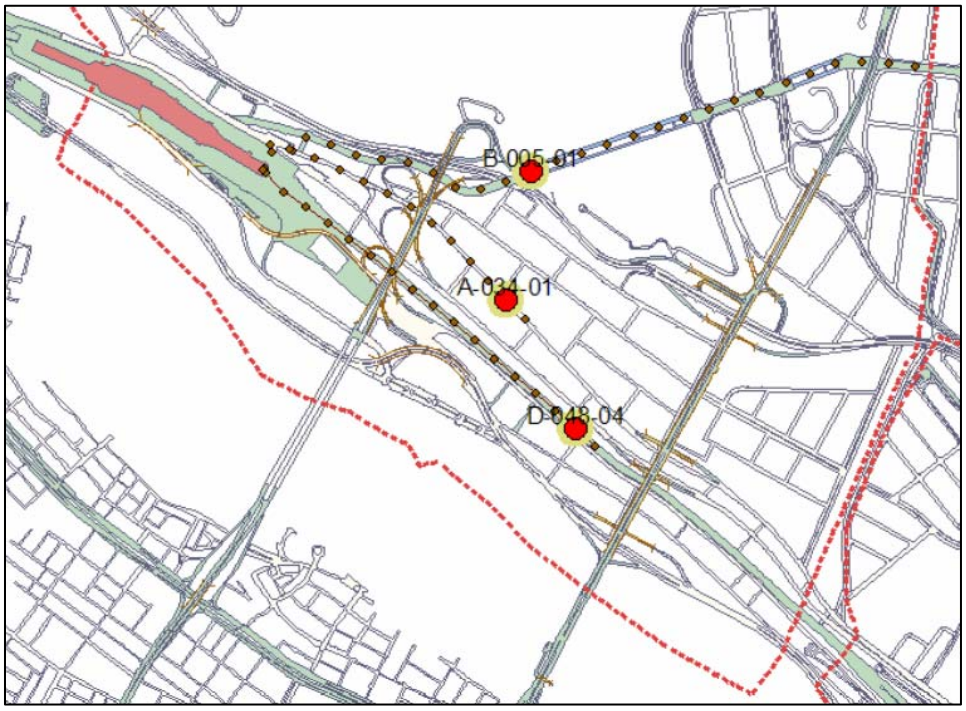

Figure 10: Simulating three groups of pilgrims going to Jamart

A tracking analysis software (Tracking Analyst extension from ESRI) is used to create a spatial-temporal simulation of movement to and from the Jamarat area. In this software the user can visualize the movement of pedestrians within a specified time window in the future (ESRI, 2005). In this research the software is used to visualize possible overcrowding problems built environment. To visualize crowding peek times at the Jamarat area the script colors the Jamarat bridge according to the number of pilgrims who reached this area. Figure 11 is used to represent the level of density and to predict overcrowding times. Figure 11 also shows the movement of groups to and from Jamarat area and the status of crowding at the Jamarat area.

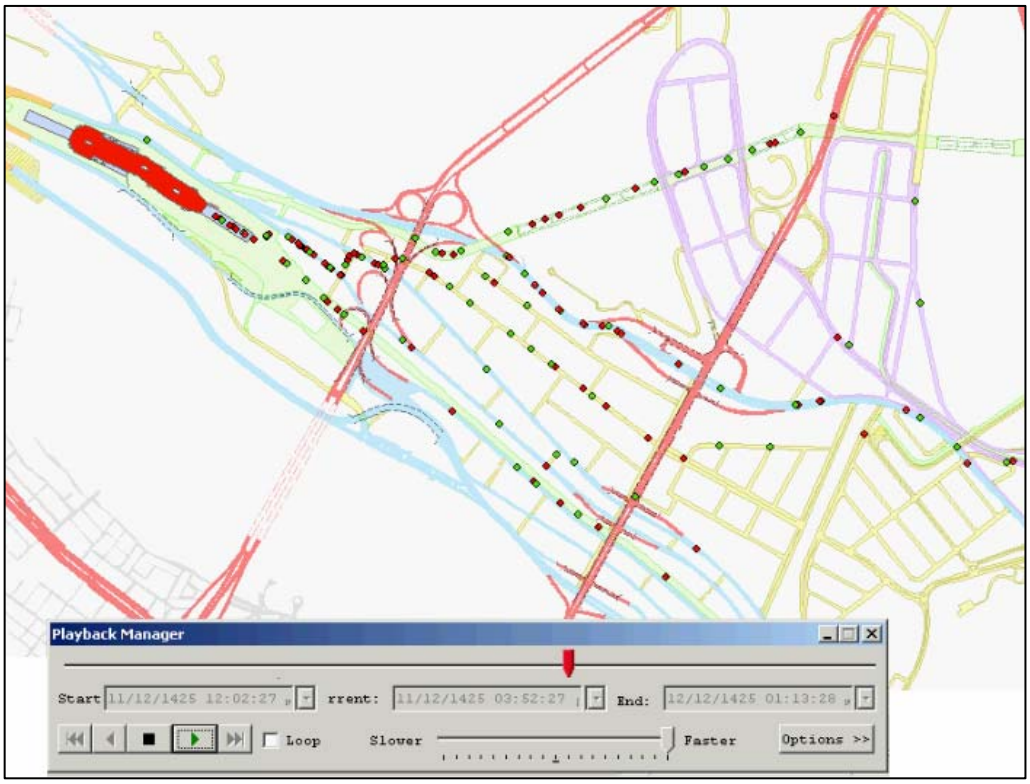

Figure 11: Movement of groups and the status of crowding at the Jamarat bridge

The approach described above can be utilized for rescheduling to reach an optimum schedule to with reduce overcrowding problems. Of course there are other factors needs to be investigated such as pilgrims different preferences and behaviors. These other factors can be included in a further research work. This research takes into consideration the spatial and temporal constraints but it is open to capture other factors such as social.

3 CONCLUSIONS

This paper has demonstrated an approach for spatial-temporal visualization of pedestrian movement from and to the Jamarat area. The approach could help urban planners and designers to better understand and analyze the behavior of pedestrians going to and returning from the Jamarat area. The approach can be utilized to discover spatial bottlenecks facing pedestrian movement. These bottlenecks in the traffic network may require urban design and planning solutions.

In addition, the approach can be utilized to produce a better schedule of pedestrian movement in Mina before the Hajj season. Different scenarios can be generated based on the temporal and spatial constrains of pilgrims

movement in Mina. The approach described in this research can be used to evaluate these scenarios. The evaluation will discover peak times in the Jamarat area according to the different timing schedule. Then modifications can be done to smooth the these peaks across the given span of time. This could lead to a schedule that has been tested and may reduce overcrowding problems in the Jamarat area.

Another important use of such approach is to evaluate the design of the urban environment in Mina. An urban designer and planner could utilize this approach to investigate the spatial distribution of tent camps. The interrelationship between the traffic network and housing distribution is an important concern that can be analyzed by such approach. This could propose redistributing pilgrims to avoid overcrowding. In this direction the spatial dimension needs to be investigated.

Future work on this topic include simulations that capture other factors affecting the pattern of human walking. This includes additional indirect interactions between pedestrians which are caused by environmental changes and their influence on human walking behavior (Helbing et. al. 2001).

ACKNOWLEDGEMENTS

The author would like to thank Eng. Mohammad Abdulhadi for his help in writing the code for the prototype implementation of the proposed algorithm developed by the author for this research project.

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