

Location Analysis of Mina Site: One of the Most Crowded Areas at Hajj

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Abstract

Crowd control is a security practice that is usually implemented to manage public activities. The human surveillance and security control are not automated and consume time, effort, and financial resources. In this research, we target a facility that is dedicated to complete Islamic pillar in Makkah, Saudi Arabia. The area of Mina spans over 20 Kilometers and approximately two millions people stays there for three days to complete their religious duty. In 2015, Mina has witnessed a crowd incident crash that caused the death of almost 700 people and over 800 injuries. We use different Geographic Information Systems (GIS) techniques to analyze the area in order to prevent future incidents.

Keywords: Hajj, Mina, Crowd, GIS

1. INTRODUCTION

Public gatherings like street fairs, music festivals, stadiums and public rallies usually involve practices of crowd control. Crowd control is a security practice that is usually implemented to manage public activities. Outbreaks of group movement within a large crowd can result in harm or death to humans and damage to facilities. Hundreds of fatalities can happen if crowd involves fights and riots. Death cases from suffocation or affray during crowd crashes are common. Yet, crowd control can be used to prevent crowd fatalities. The current practice is to use security guards as well as police officers to prevent weapons and drugs being brought into a venue. However, this is considered as human intervention of the current location's set up. Location characteristics can largely impact the crowd control practice positively or negatively. The location's entrances, exits, closeness to services and transportation approximately can influence the crowd management policies and help prevent fatalities. In this paper, we present location analyses for

the Mina area which is situated 5 kilometers to the east of the Holy city of Mecca; a facility is used to complete Hajj duties in Makkah, Saudi Arabia (see Figure 1). The idea was conceived as many crowd incidents have been detected in the location where more than two millions of people from around the world are accommodating a space area of approximately 20 km² (Hajj 2015, 2016; A look at major hajj-related accidents in Saudi Arabia, 2015) (Figure 2).



Figure 1: Mina area (tent city)

In the valley of Mina is the [Jamarat Bridge](#) (Figure 2), the location of the ritual of the Stoning of the Devil, performed between sunrise and sunset on the last day of the Hajj. Mina is the place where pilgrims throw stones, commemorating the occasion that the Prophet Ibrâhîm (Abraham) stoned the Devil that came between him and the command Allah had set him. Many pilgrims spend their first night in the Valley of Mina. This ritual occurs from the eighth to the twelfth day of the Hajj. (Pillars of Hajj, 2016)



Figure 2: Jamarat Bridge

In 2015, "At least **717 pilgrims were killed** and **863 were injured** in a crush at Mina outside Mecca, Saudi's civil defense reports." *Reported by Al Jazeera* (More than 700 killed in Saudi Hajj stampede , 2015). This incident is not the first crush at Mina but in terms of severity, the number of people died and injured is catastrophic. In this paper, we perform analyses on the accident location and then we propose the best locations to set on camps in Mina in order to prevent future crowd incidents. The location analysis is performed according to location approximate to the following criteria:

- **Services**
- **Jamarat bridge entrances**

Services category combines the following: hospitals, police stations, civil defenses, information centers, guidance fields, Islamic awareness centers, red crescent centers, clinics, and train stations. This granular division helps in deciding what is exactly missing for a certain camp location and may have direct connection with crowd incidents.

According to the Guardian, Oct 3, 2015:

The list of crowd disasters associated with the Hajj in Mecca, Saudi Arabia, is especially appalling. In 1990, 1,426 people were crushed to death, in 1994 it was 270, in 1998 it was 118 (at least), in 2001 it was 35, in 2003 it was 14, in 2004 it was 251, in 2005 it was three, in 2006 it was 360 (at least). More surprising than the 769 deaths so far confirmed from last month's crush is the fact that the Hajj got through eight consecutive quiet years. (Hajj crush, 2015)



Figure 3: A street full of pilgrims in Mina

Crowd incidents can happen anywhere, anytime, and yet, it can be controlled with human or new sensor devices. In fact, many studies have shown that certain precautionary practices can be implemented to determine the capacity of a place and direction of pedestrian flow. "It is found that the reduction of pedestrian flow depends on the shape and the length of the narrowing. The maximum observed flow of the corner (about 1.45 (m s)⁻¹) is the lowest in all facilities studied, whereas that of the short narrowing is highest." (Zhang & Seyfried, 2014)

Looking at the resources of incidents, Halabi (Halabi, 2006) mentioned that overcrowding and bad management caused crowd disasters. "...these disasters are characterized by poor communications prior to, during and in the aftermath of an incident, which it is very often the victims, rather than the designers and managers of crowd settings who are blamed" (Cabinet Office, 2009). Illiyas et al. (Illiyas et al., 2013) mentioned that human stampedes are the most common danger at mass gathering events. "They are characterized by massive flow of individuals in a crowd in response to a danger. They could additionally result in death, due to suffocation under the high pressure that is caused by the push in that crowd." (Owaidah, 2015)

Most of previous research pointed to the problem of overcrowding and human stampedes and presented management methods such as human intervention and technological tools. Specifically, the research by (Owaidah, 2015) presents Mobile Augmented Reality application where the information about crowds' movements and pilgrims' locations is exchanged and communicated to authorities.

In this project, the focus is on approximate location of different camps to services. Mainly we focus on location of crowd incidents and the distance of different camps to the incidents and services. The services are hospitals, police stations, civil defenses, information centers, guidance fields, Islamic awareness centers, Red Crescent centers, clinics, train stations, and mosques. The services are assigned different weights dependent on its importance for crowd control using weighted overlay tool.

2. PROBLEM DEFINITION & RESEARCH QUESTIONS

Crowd control is a practice essential for public spaces or any open event. Due to the huge volume of people coming to Mina, more crowd control practices are needed. The camps facilities and location related information might have impact on incidents. The lack of services in certain locations may increase the probability of fatality.

The goal is to analyze the location and incidents, trying to link location approximate of camps and services to incidents. This analysis is performed in order to establish criteria to categorize camp locations and identify suitable places for setting new camps. This research helps in planning and developing the area of Mina for camps.

Research Questions

Q1: Can we create criteria for camp locations' safety?

Q2: How are camps locations are classified based on the established criteria?

Q3: Is there a relationship between the stampede location and the distance of services? (Delay access)

In this paper we want to investigate how location approximate to services may influence the safety of camps. We want also to identify the least and most reliable areas to set camps. We intend to geographically represent correlations between stampede locations and how far are the services. Thus, we present suitable places for future development to set up new camps and at

the same time the current areas that lack necessary services.

In the Hajj, pilgrims are accommodated in camps with dedicated area for each nationality. Camps are divided into eight: Internal, Gulf, Iran, South East Asia, Southern Asia, Africa, Arabs, and Australia, America and Europe. This division of camps is called the national establishments (Figure 4).



Figure 4: The establishment Area in Mina

3. DATA SELECTION AND ACQUISITION

Data	Source	URL
Makkah streets	Open Street Maps	http://www.openstreetmap.org/#map=5/51.500/-0.100
Camps Area	Open Street Maps	http://www.openstreetmap.org/#map=5/51.500/-0.100
Mina area and service distribution	Saudi Scout	http://www.spa.gov.sa/galupload/norm/89572_1320254380_9712.jpg
Hajj incidents through years	BBC news	http://www.bbc.com/news/world-middle-east-34346449

Table 1: Data Selection and Acquisition

The base map is retrieved from Open Street as map package.

The camps area, services and facilities is projected using an image file retrieved from Saudi Scout illustration map (http://www.spa.gov.sa/galupload/normal/89572_1320254380_9712.jpg) (Figure 5). The limitation of data availability is a problem that we overcome with digitization of camps, incidents, and services using create features tool in ArcMap.

For Hajj incidents that were manually entered in Excel, we created a feature layer that projected the location for those incidents and then joined the tables. At the beginning, data was not available. Thus digitizing was our only available option. The biggest problem is the digitizing process that took a lot of time to be completed. The lack of available digital maps for the area made us dedicating time to produce the digitized map. Another problem is the exact location of the incidents as news just pointed to the area but not the exact longitude and latitude.

This analysis lacks also the data for the elevation contour of the location. As we still looking for a provider to such data this may impose a challenge on determining precisely location suitability for setting camps.

We used mostly **ArcMap**, which runs on the Windows platform, for digitalizing and entering data. "ArcMap is the primary application used in ArcGIS and is used to perform a wide range of common GIS tasks as well as specialized, user-specific tasks." (What is ArcMap?, 2016)

we have also used Excel to manually enter incidents data. For sharing and saving data, we used **ArcGIS** with a shared group privilege to exchange the most recent updated map. ArcGIS Online is a Complete, Cloud-Based Mapping

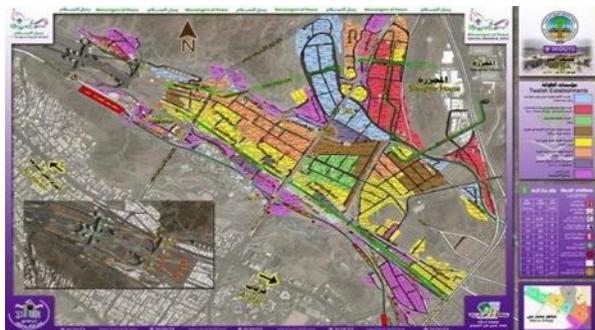


Figure 5: Scout Map of Mina Platform.

For documenting the Hajj incidents through years, we used **Excel** to enter and import data into **ArcMap**. We chose ArcMap as we mostly do location analysis and we need its variety of tools that are available for analysis. The incidents data table in ArcMap is shown in Figure 6.

OBJECTID*	SHAPE*	NAME	DATE	COMMENT
1	Point	<Null>	9/24/2015	Crowd incidents resulted in 717 and injuries of 86
2	Point	2006	1/12/2006	Crowd at Jamarat area resulted 364 deaths
3	Point	2004	2/1/2004	Crowd resulted in 251 deaths
4	Point	2003	2/11/2003	Crowd resulted in 14 deaths
5	Point	2001	3/5/2001	Crowd resulted in 35 deaths
6	Point	1998	4/9/1998	Crowd resulted in 118 deaths and more 180 injuries
7	Point	1994	5/24/1994	Crowd resulted in 270 deaths
8	Point	1990	7/2/1990	Crowd resulted in 1426 deaths

Figure 6: Incidents data displayed in ArcMap

4. METHODOLOGY

Digitization

Due to the lack of digital data of the Mina area, we needed to digitize the whole area of this neighborhood. Furthermore, we needed to digitize the camps national establishments (divisions of tents that is dedicated for certain nationality) for accurate data representation and for precise distance measurement. There are eight national establishments:

1. Internal (Rose color)
2. Gulf (Gray color)
3. Iran (Green color)
4. South East Asia (Light blue color)
5. Southern Asia (Yellow color)
6. Africa (Brown color)
7. Arabs (Orang color)
8. Australia, America, Europe, and Turkey (Red color)

Each camp has set of tents and we digitize each tent in order to measure the accurate central point for the camp.

We also digitize the services such as hospitals, police stations, civil defenses, information centers, guidance fields, Islamic awareness centers, Red Crescent centers, clinics, train stations, mosques, Jamrah bridge entrances, and holy Makkah (Appendix A).

In order to investigate how services and camp locations are related to Hajj incidents in Mina, we digitize the Hajj incidents locations from 1990 to 2015.

Buffering

To analyze the available services surrounding the Hajj incidents areas, we implement "Multiple Ring Buffer" from "Proximity" category under "Analysis Tools". This tool allows to set different diameter to count the available services on each. The distance we selected are: 100 meters, 200 meters, 300 meters, 400 meters as people relies on walking to reach those services within the incident location. Figure 7 shows the multiple buffering for 2015 and previous years incidents in Mina. In figure 6, red stars are the incidents and the green is (100 meters); orange is (200 meters); blue is (300 meters); green is (400 meters).



Figure 7: Buffering for the incident

As we implement the buffering, we found that within 100 meters in 2015 incident, there are no services available, within 200, there is a single civil-defense, within 300, there are 3 police stations, a Red Crescent, 2 Islamic Awareness centers, a guidance, and a hospital. Within 400 meter, there are: one train station entrance, 3 civil defenses, and a Red Crescent. There are Holy Makkah centers (Imarah) within 200, 300, and 400 meters.

We did also buffering on the Jamarat entrance (Figure 8) because it serves as the segway from all camps to the Jamarat. Pilgrims are obligated to visit the Jamarat place for three days to throw pebbles at three walls (formerly pillars). To allow easier access to the Jamarāt, a single-tiered pedestrian bridge called the Jamaraat Bridge was built around them, allowing pilgrims to throw stones from either ground level or the bridge. The Stoning of the Devil ritual in the Jamarat is considered the most dangerous part of the Hajj, as sudden crowd movements on or near the Jamarat Bridge can cause people to be crushed. On several occasions, thousands of

participants have suffocated or been trampled to death.

There are seven entrances from camps to Jamarat and to analyze the services surrounding

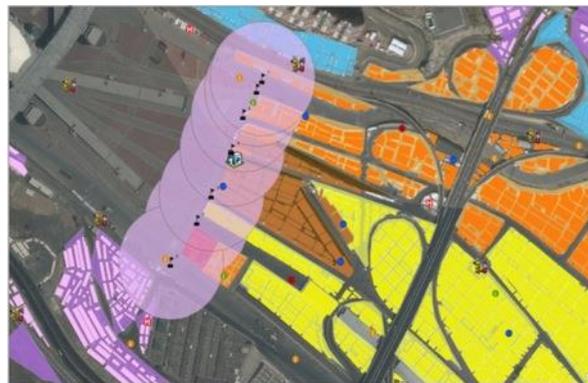


Figure 8: Jamarat Entrance Buffers

those entrances, we used 100 meters single buffering (Figure 8). We chose single buffering because we need to measure each entrance's accessibility to services. The high two eastern entrances each have one civil defense, an information center, and a guidance. The third has a police station, an information center, and guidance. The fourth shared information center, a clinic and a shared police station with the third. The fifth shared police station and shared clinic. The sixth share a clinic and guidance. The seventh has only the shared guidance.

Measuring Distance

In order to determine the suitability of each location in Mina, we have been through number of steps.

First, we ran a tool called Euclidean Distance under the category Spatial Analysis, between the boundaries of Mina and all the 13 services. This tool measures ordinary, straight-line distance between two points. For example, the distance between the location and all the three train stations in Mina. For example, Figure 9, shows the result of using Euclidean Distance for the train stations. And it shows the difference distances which yellow color represent the closer to the station and the blue color is the furthest distance. We repeated this process for each type of the services.

Then, we used another tool called Reclassify under the Spatial Analyst, in order to reclassify the location based on the distance from the center of each type of the services. Figure 10, is an example, of how to reclassify the distance from the train station. Number 1 always

represents the range of worst area, and number 9 represents the best area. Here we determine the distance that number 1 is represented as the worst, which is the closest surrounding area (0-50) meter around each train station. Number 9 represents the best area that is not so close and noisy and at the same time easy to access, this area range fall in between 50-500 meters. And Figure 11 shows the classification of areas to four different distances, which is the result of using the reclassification tool.

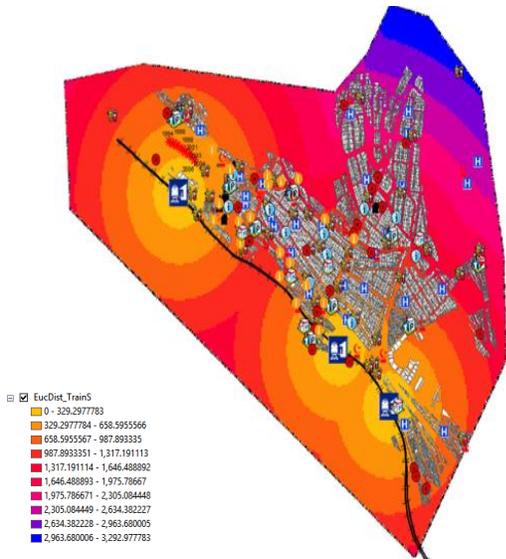


Figure 9: Euclidean distance of Train Station

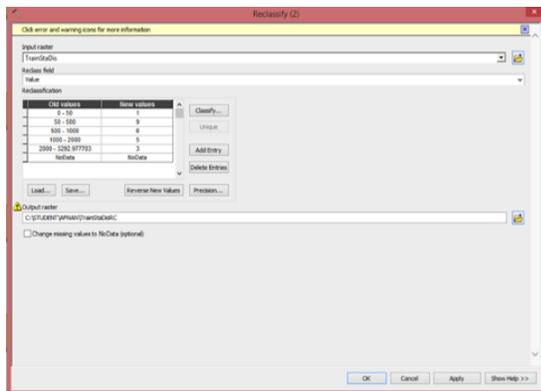


Figure 10: Reclassify criteria for train stations

Finally, to assign priorities to each service that we have in the area, in order to come up with the suitable locations. We used tool called Weighted Overlay, which also fill under the

Spatial Analyst. The purpose of using this tool is to determine the priorities, for example, the information center is important, but not as much as police stations. Figure 12, shows how to enter and determine the priority for each service.

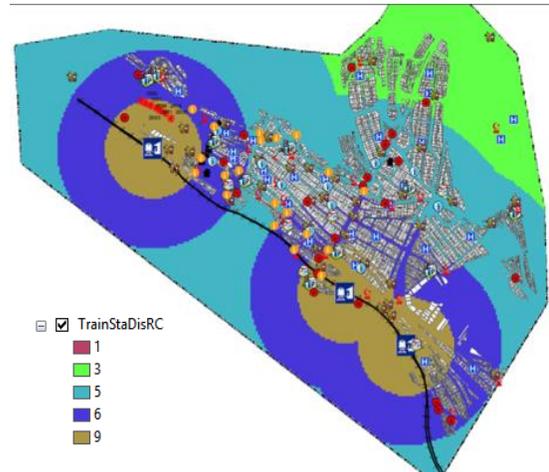


Figure 11: Reclassifying Train Station

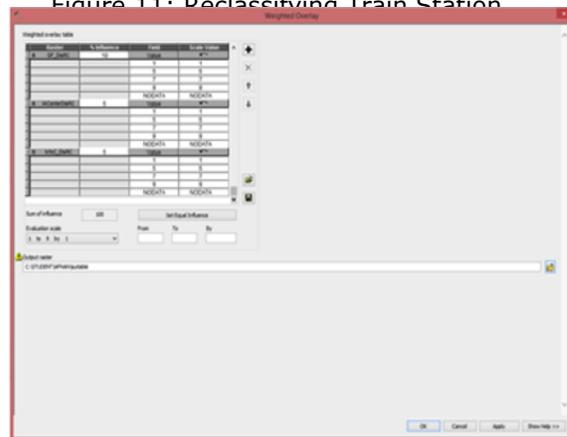


Figure 12: Weighted Overlay

5. RESULTS

We have realized that the lack of services and the distance approximate is an overlooked factor in crowd management. The area we analyzed and the data representation show the suitable areas to set up camps and the least desirable areas (Appendix B & C). This analysis is based on each camp's distance from services, approximate distance from Jamarat entrance, and the weighting factor that we assigned for each criteria.

The least and most desirable areas are reported corresponding to the closeness to services and

how services and tents should be distributed. The analysis allows more understanding to where services in critical locations, such as Jamarat entrances, should be located. The buffering technique we used on the area and the surrounding service has provided insightful awareness to where incidents could be avoided with adequate understanding of services allocation. In order to answer the first and second question from the three research questions that we have, first we need to address and answer the third question, "Is there a relationship between the stampede location and the distance of services?" which could delay any help in case of any emergency situations as noted as delay access.

In fact, we have two main stampede locations that most fatality happened in them. The first one is Jamarat Bridge which is the location where stampedes incidents in 1990, 1994, 1998, 2001, 2003, 2004, and the last one at 2006 are happened. The second is Mina's Street 204 where 2015 incident happened. By using Multiple Ring Buffer tool from Arcgis, figure 6, shows the location analysis for eight stampede locations in Mina's area. The tool creates multiple buffering from the central of the stampede locations. Red stars represent the incidents and the green is (100 meters); orange is (200 meters); blue is (300 meters); green is (400 meters).

As a result, figure 6 clearly can shows a kind of a relation between how far the services from the stampedes, or may be the lack of them was one the reasons that caused stampedes. Which answer the third question from the research questions under the problem definition section. Figure 7, shows the results of running single buffering tool on the entrances to Jamarat Bridge. Our purpose from figure 7 was, since the entrances area that leads to the Jamarat Bridge, is an area that fill between the main two locations is like a "bottleneck", which all the earlier stampedes happened there. After running the tools, the results were obviously clear there is a good number of services in the 100 meter around the main entrances. This result can support that there is a relationship between the stampede location and the distance of services. The distance of the services such as the guidance centers can be one of the reasons that cause stampedes when people lose their direction in a new crowded place.

Furthermore, Appendix C, is a result that shows the suitable areas in Mina which are shown in

green color and less suitable are in brown color. And we mean by suitable areas, areas that are close to the entrances of Jamarat Bridge, have the enough number of services near, and the services is in a good measured distance. Appendix C, is a result running the Model Builder (Appendix B) in order to identify suitable areas in Mina depending on the number of established criteria that we mentioned before. So, appendix C can be a good guide that can help responsible people to take a decision, such as where are the areas that need more new services (brown color area), best areas that be suitable to build new camps on it, and more.

Finally, after answering the third and second questions we are now able to answer the first question, which is "Can we create criteria for camps locations' safety?". And the answer is yes. After all the information we have and running number of analyses tools, the map shows suitable areas for safe camps.

6. CONCLUSIONS & DISCUSSION

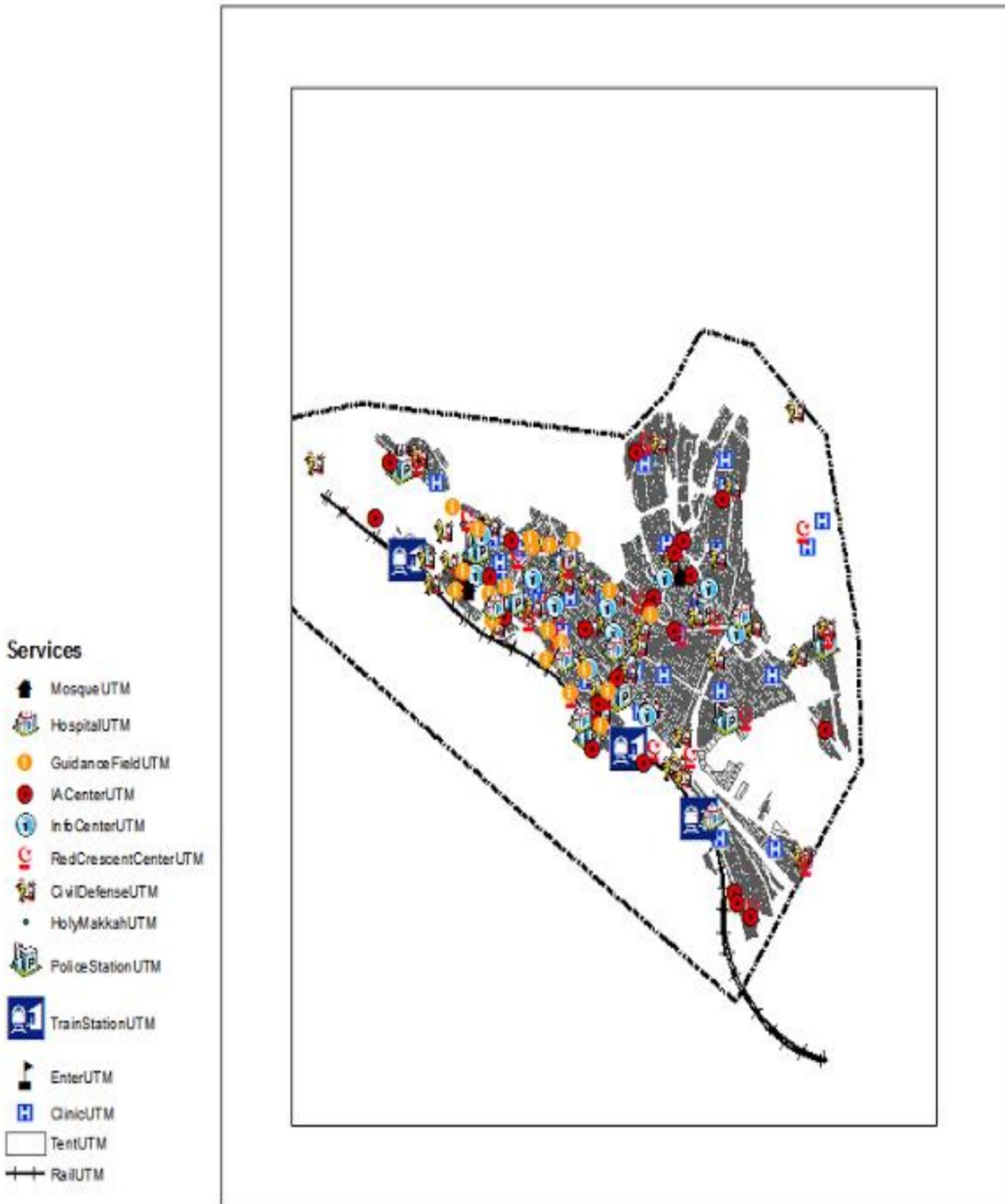
In this project, we used different techniques to analyze the implication of services' locations on Hajj incidents. This analysis allowed us to realize the suitable areas to set up camps. Also, through the analysis, we realized the areas where services are in far distance and may not suitable for setting camps. Digitizing each tent in the camp was a tedious process but we hope that will help future studies to not reinvent the wheel. This step assists in finding the centroid for each national camp then measure the distance from each camp to services in order to identify convenient locations for camps that are accessible to services. In our analysis, we also shed light on the Jamarat entrances to analyze the services as it considers the bottleneck when pilgrims walk for a Stoning of the Devil ritual in the Jamarat.

7. REFERENCES

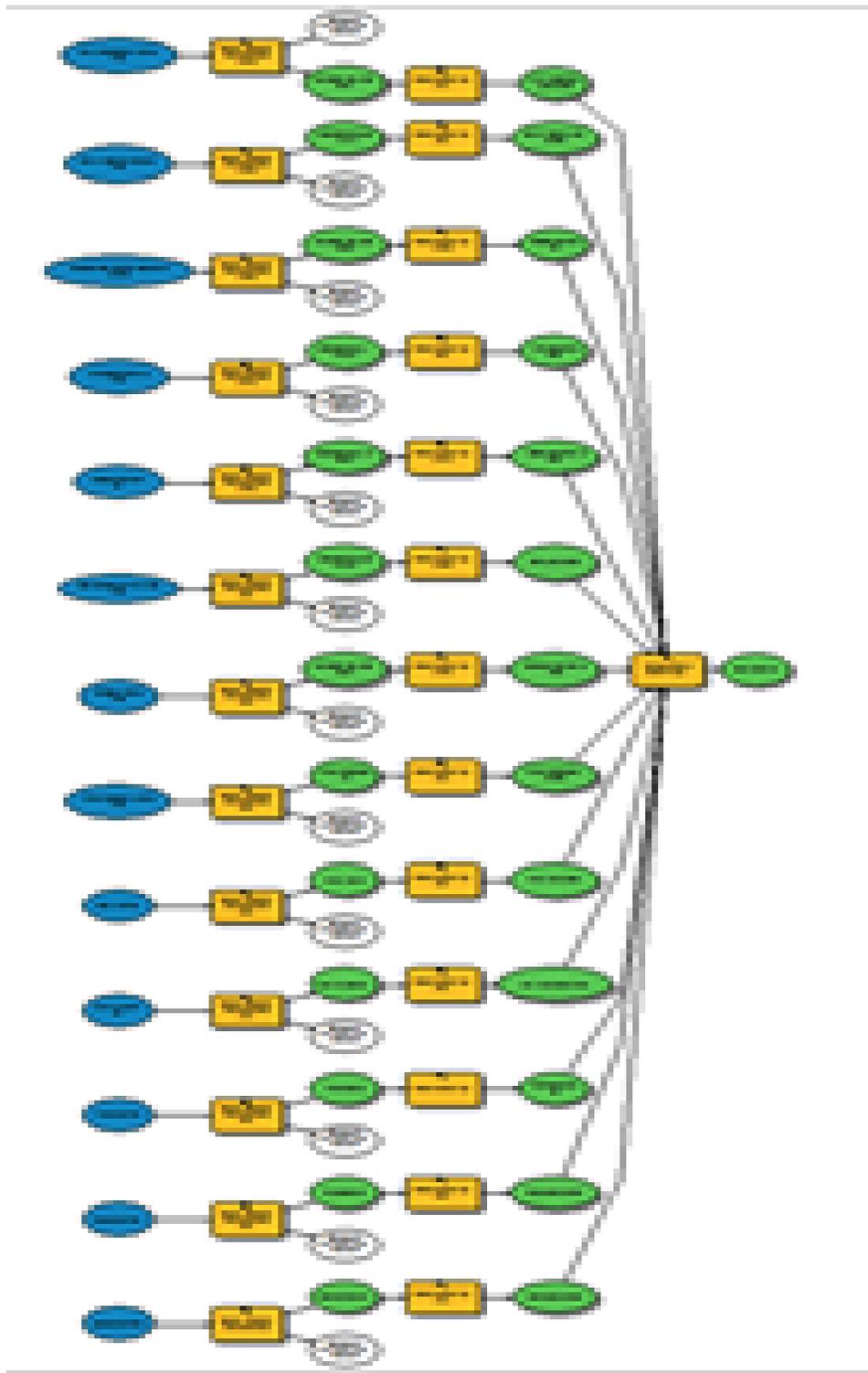
- A look at major hajj-related accidents in Saudi Arabia (2015, September). In yahoo.com. Retrieved April 12, 2016, from <https://www.yahoo.com/news/glance-major-hajj-related-incidents-saudi-arabia-085510881.html>
- Cabinet Office, 2009 (B), Understanding crowd behaviors: Supporting evidence. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/

- 192606/understanding_crowd_behaviour-supporting-evidence.pdf
- Halabi, W 2006. "Overcrowding and the Holy Mosque, Makkah, Saudi Arabia", PhD thesis, Newcastle upon Tyne, UK.
- Hajj 2015: 2 million Muslims gather for world's largest annual pilgrimage - See more at: <http://www.readthespirit.com/religious-holidays-festivals/hajj-2015-2-million-muslims-gather-for-worlds-largest> (n.d.). In readthespirit. Retrieved April 12, 2016, from <http://www.readthespirit.com/religious-holidays-festivals/hajj-2015-2-million-muslims-gather-for-worlds-largest-annual-pilgrimage/>
- Hajj crush: how crowd disasters happen, and how they can be avoided (2015, October 3). In theguardian. Retrieved April 13, 2016, from <http://www.theguardian.com/world/2015/oct/03/hajj-crush-how-crowd-disasters-happen-and-how-they-can-be-avoided>
- Illiya, F, Mani, S, Pradeepkumar, A & Mohan, K 2013, "Human stampedes during religious festivals: A comparative review of mass gathering emergencies in India", International Journal of Disaster Risk Reduction, vol. 5, no. 1, pp. 10-18.
- More than 700 killed in Saudi Hajj stampede (2015, September). In Aljazeera. Retrieved May 4, 2016.
- Owaidah, Almoaid A. (2015) Hajj crowd management via a mobile augmented reality application: a case of The Hajj event, Saudi Arabia. MSc(R) thesis.
- Pillars of Hajj (n.d.). In Hajj Now. Retrieved April 12, 2016, from <http://www.hajjnow.com/book/pillars.shtml>
- What is ArcMap? (2016). In ArcGIS. Retrieved August 18, 2016, from http://desktop.arcgis.com/en/arcmap/10.3/main/map/what-is-arcmap-.htm#ESRI_SECTION1_B088FC4AC7194A55B10799B6A2C0FC8C
- Zhang, J., & Seyfried, A. (2014). Quantification of bottleneck effects for different types of facilities. Transportation Research Procedia, 2, 51-59.

APPENDIX A: Mina area services



APPENDIX B: Model Builder for identifying suitable areas in Mina



APPENDIX C: Suitable areas are shown in green and less suitable are in brown

