Applications of GIS in Urban Planning and Transportation: the case study of Al Kaakiyyah in the Holy city of Makkah

Yaser Abdullah Attar
MsC of GIS, King Abdulaziz University, FAL of Jeddah, Dept of Geography and GIS
Mohsen DHIEB,
Professor of Mapping Sciences, King Abdulaziz University, FAL of Jeddah, Dept of Geography and GIS

Abstract

Makkah has a unique respect and value in the Muslim world. It hosts the Holy Mosque and welcomes every year millions of visitors and pilgrims from all over the world and t
his number is increasing incessantly. The high density of inhabitants is also increasing despite topographical and climatic constraints. This increase of resident and occasional population of pilgrims and its incessant movement cause huge traffic congestion in many places. Enlargement of Al Haram suburbs and displacement of population, central buildings and transportation network were the main planning responses to this crucial issue. But these measures reveal insufficient to solve the problem of accessing the Holy Mosque and the downtown.

In this research, the authors consider the case study of Al Kaakiyyah intersection, one of the most crowded places of Makkah. It aims to improve road traffic fluidity from and towards the Holy Mosque and other places by using this central focal crossroads It is also conducted in several steps: collecting data and organizing (transportation data, maps, statistics on users, studies and published works about Makkah and its network); examining the current situation of Makkah and AlKaakiyyah; implementation of simulations scenario to measure to what extent the traffic cab be improved at this place.

Results of the study yield important changes improving the fluidity of traffic, especially during the rush hours. Of course, solutions for the long term must be global and imply radical modifications in land use, roads trajectories, and transportation network and management, but at the short term, enhancing circulation by rethinking and redesigning

places by the use of dedicated software may yield to better urban planning and transportation traffic.

Keywords: GIS, Urban Planning, Transportation, Makkah, Al Kaakiyyah crossroads.

1. Introduction

he city of Makkah is the third largest city in Saudi Arabia (almost 2 million inhabitants). Considered as the holiest place Makkah for Muslims, it attracts yearly several millions of visitors and pilgrims, legally or illegally, especially during the two Holy Months of Ramadan and Hajj, and its Holy Mosque located in Al Kaaba attracts thousands of them to pray 5 times a day. This situation provokes huge movements and daily traffic that Saudi authorities try to solve in the best way.

Even though a wholistic solution should be considered in planning transportation, finding local solutions to problematic traffic places can help. The Al Kaakiyyah crossroads is one of the most crowded places since many roads converge to it and lead pedestrians and drivers to reach the Downtown and the Holy Mosque.

The main objectives of this research are to examine the relation between population distribution, the transportation network, the land use and urban planning; to apply GIS and dedicated traffic software management on urban planning and transportation in Makkah from; and to suggest some recommendations to improve GIS application in urban planning and transportation in Al-Kakiyyah case study.

First, we intent here to present the study area of Makkah, the current situation of planning and transportation but we focus on Al Kaakiyyah place. Second, we review the design of this place and the generated traffic flows, by implementing a GIS integrating land use, transportation and planning data. Third we suggest modifications in the transportation system network at this place by simulations of traffic flows based on scheduled times and specific days that reveal interesting possible decrease of traffic jams especially during the rush hours. This may help the Vision 2030 goals aiming to increase the number of Umrah visitors from 8 to 30 million.

2. Previous studies and methodology

2.1. Previous studies:

Many previous studies were used. Basically, we cite :

- The Holy Makkah Municipality and (DAMR) studies which produces maps, reports, various plans such as “The Model of the Comprehensive Plan of Transport and Traffic 2015”, “Updating the Model of the Comprehensive Plan of Transport and Traffic 1437H”, “The Comprehensive Plan of Public Transportation in Makkah and Al-Mashaeer 2012,” and “The Improvement Plan for Al-Mashaeer”. These studies offer information and data, which have played an important role in the analysis process. They touched many points such as network, social aspects and economic issues.
- The Urban Growth and Transport in Jeddah (M. Al Joufie, 2012) analyzing the spatial-temporal relationship between urban growth and transportation to support urban and transportation planning in rapidly growing cities.
- Dedicated textbooks such as (Longley P. A., Goodchild, M. F.M Maguire D. J., and Rhind D. W., 2005, chapter 4,); Transportation GIS (N. M. WATERS, 2005, chapter 59); (A G-O YEH, 2005, Chapter 62); (Subash Chandra.M, Rajalakshmi.S, Rajakumari, Madhavan. K.D, 2008); (Ibrahim Alkhaldy, 2009): (b Baha Alshalalfah, Amer Shalaby, Steven Dale, Fadel Othman 2015); 2.1.7 Mechanisms of Urban Growth of Makkah Al-Mukarramah (Nuzha Yaqzan Aljabiri, 2013); (Abd El Kawy, 2004); (Abdel Baqi 1983); (Muhammad Abdulaziz Abdul Majeed, 2000); (Shawqi Al-Abdallat, 1991).

2.2. Methodology

The methodological steps are as follows:

- Collecting data: It consists in collecting information, data, maps, statistics, studies and published works about Makkah and its network. This helps to get a better understanding of the current situation, the feature of Makkah, the current and the future transportation requirements, and the expected developments.
- Studying the current situation: Based on the available data of natural conditions, land use, urban growth, transportation and traffic volume, the results of the previous studies, and all what let deciders

having clear ideas about Makkah city, and making decisions engaging its future, with links to transportations.

- Implementation and simulation: After studying the current situation for the case study of Al Kaakiyyah, the authors had to come up with some solutions, and then realized a simulation by using some specialized software (VISUM) to get better solutions for the short term.
- Then, results are discussed.
- Recommendations are suggested for the long-term solutions which are one of the GIS applications in urban planning and transportation. Besides the usual modules of ArcGis such as ArcCatalog, ArcMap and ArcScene, two other software were used to implement the Al Kaakiyyah GIS : AutoCAD to draw the roads network in Makkah and its categories based on the hierarchy of the roads network; PTV VISUM for traffic analyses, forecasts, and GIS-based data management and SYNCHRO for modeling and optimizing traffic signal timing to minimize delays.

3. Study Area:

3.1 Overview

Located in the west of Saudi Arabia and surrounded by the Lower Assir Mountains at a height of 300m above mean sea level, Makkah has a very rude climate especially during summer that accentuate difficulties of traffic circulation, when the temperature may reach 50 degrees C. It is worth to note that 47% of its 2 million inhabitants are non-Saudis and reside mostly in central districts of the city (General Authority of Statistics, 2016). Number of pilgrims may vary from one year to another: in 2012, about 3.2 million pilgrims in 2016, about 1.9 million pilgrims (domestic and foreign pilgrims). Six main corridors and more than 29 thousand vehicles carry domestic pilgrims Saudi (General Authority of Statistics, 2016) (Figure 1).

Figure 1: The Six Main Corridors to Enter into Makkah

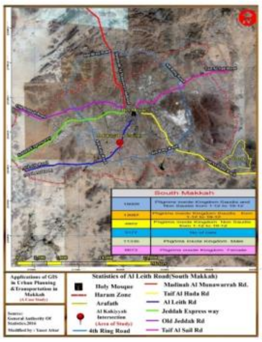


Figure 2: Statistics of Al Leith Road (South Makkah)

In Hajj 2016, around 11% of vehicles that carried the domestic pilgrims came from the South Corridor (General Authority of Statistics, 2016) where Al Kaakiiyyah is located (Figure 2 and table 1).

Table: 1 General Information about Makkah

Makkah			**Holy Zone**		
1	Urban zone area 1450H	1210 m2	1	Mina area	7.8 km2
2	Height above sea level	300 m	2	Muzdalifa area	11.6 km2
3	Holy Makkah Municipality supervision zone	12752 km2	3	Arafat area	12 km2
4	Haram zone	556 km2	**Approved plans**		
5	Central zone area	6.4 km2	1	No. of approved residential plans	415 plans
6	Mountain zone area	465 km2	2	No. of residential lands	260331 lands
7	Population (2010)	1578722	3	No. of approved workshops and warehouses plans	21 plans
8	Estimated population (2020)	2189169	4	No. of workshops and warehouses lands	7802 lands
9	Makkah districts	60	**Parks**		
10	Holy Mosque area (current)	365000 m2	1	No. of parks (executed)	200 parks
				Parks area (executed)	2.85 km2

Urban areas in Makkah are planned to accommodate higher density of population, increase traffic, and urban developments. Urban areas are also designed at the human scale to accommodate multiple modes of transportation that connect land use types (residential, commercial, industrial, parks, slums... etc.) in Makkah together. The size and layout of the basic urban areas are based on how far a person will walk to reach services. It is the key to the success of urban areas in Makkah.

The 60 slum areas of Makkah mainly located at central places are another challenge that urban planners face in Makkah. Hosting a big number of workers and small businesses. Urban planners try to integrate with the structure plan for Makkah. City planners should also consider and improve the city in many sectors interrelated : Urban sector which including urban development in land use, pedestrian corridors, building heights and regulations, and green areas; Roads network; Environmental issues; Services and facilities; Infrastructure but also Social and Economic sectors.

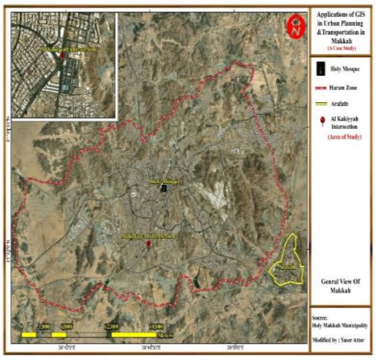


Figure 5 Holy Zone in Makkah

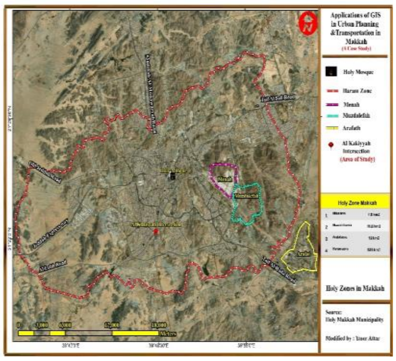


Figure 6: General View of Makkah

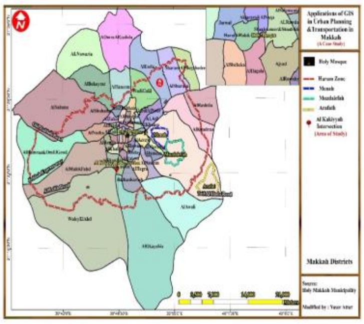


Figure 7: Makkah Districts

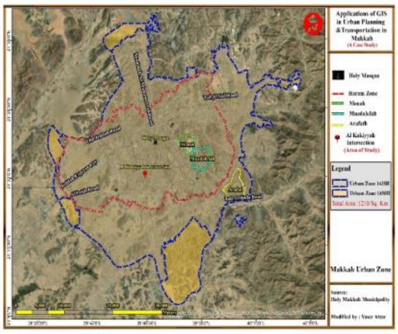


Figure 8: Makkah Urban Zoning

2.2. Natural conditions

The topography of any city has a big impact in urban planning, especially in the city of Makkah. Topography has had and still has a great impact on its urban structure. Indeed, the complexity of Makkah mountainous topography had determined its urban growth in the past, and still has an impact in its present and its future. So, the study of Makkah urban planning requires an analysis of the topographical features; this may help to determine the most important characteristics in the urban growth of the city. Topographic information is one of the basic and necessary aspects that must be considered when planning various projects. Projects planning depends on the nature of the surface aspect and topography and the impact on urbanization (Al-Shehri, Noura Saad, 2013, p59)

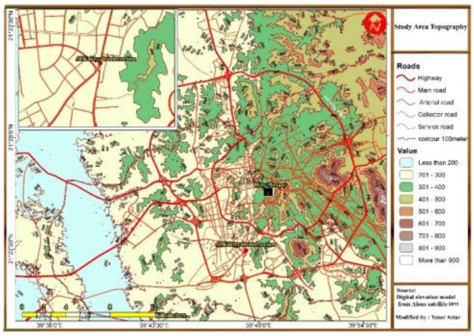


Figure 9: Study Area Topography

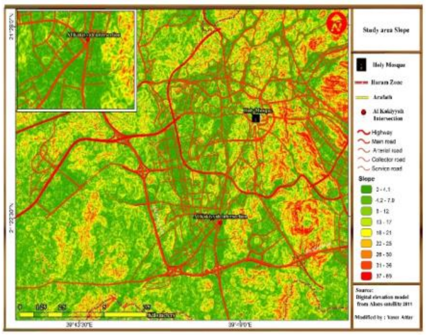


Figure 10: Study Area Slope

Studying the transport network or the movement of transport needs examining the geography of the city because of the mutual effects between them and the geographical nature, and all human and economic aspects and activities seems meaningful. The quality of transport, and the density and configuration of roads networks depend on geographical factors, whether human or natural. On the one hand, sometimes, the geographical factors stand against the human abilities, and the topography can influence the transportation system or the use of specific roads. But on other hand, these factors may facilitate the development of the transportation network and traffic. The authors will address the most important natural factors that affect the transport network as following:

Aspect affects construction costs in the regions and it is difficult to extend the roads in mountainous areas unless costly and sophisticated network; determines the road trajectories paths: and the width of the roads. Furthermore, the roughness of the surface is a negative factor in transportation, and this applies to pedestrians as well as to vehicles. The higher is the slope of the surface, the less is the ability of the vehicles drivers to drive easily (up or down). This leads to a decrease in the speed of the vehicles, which leads to increase the distance in time vector. Many transportation systems, especially large vehicles or buses cannot roll on sharp slopes with speeds exceeding 20 / hour. Figure 9 shows the how the roughness of the surface affects also the process of future expansion of Makkah urban growth, and the roads network system.

The complicated topographical character predominates over the topography of of Makkah. This complication in topography implies shortening the horizontal distances of the roads. In addition, the shapes of mountains in Makkah are different: linear as a chain; whether in north-south or east-west; relatively circular such as Jabal Thor and Jabal Al-Nour; and isolated and unique tops such as Jabal Al-Sard (Al-Shehri, Noura Saad, 2013, p59).

The slope factor is one of the geomorphological factors that city planners and road designers should consider in planning roads; planners try to avoid as much as possible steeply areas, because of the additional flattening costs, in addition to the additional expenses in delivering materials and utilities (Figure 10).

For instance, British and American cities grew up in the plains and left the slopes for hiking, tourism and protection of natural resources (Allam, 1998, p. 333). So rules were established ; the Ministry of Municipal and Rural Affairs required that the degree of slope in residential uses should not exceed (20%) 11°, and for topography, exclusiveness of Makkah, Holy Makkah Municipality raised the degree of slope up to (30%) 16.70° max (Allam, 1998, p. 333).

Therefore, the slopes were classified into two categories: less than 30% or greater than 30%, which should not be built, according to the requirements of the Holy Makkah Municipality.

Slopes have impact especially in the case of streams: the risks that roads fall down or collapse from the sides, whether by natural factors or by rocks falling from vibrations resulting from the movement of large transportation systems such as trucks (Abdulrahman Manal A., 2011, p58).

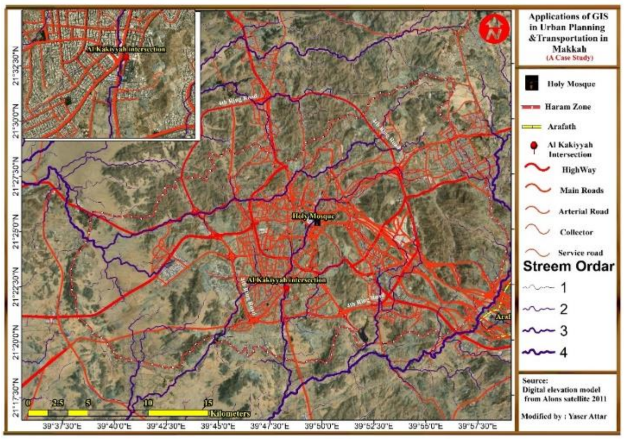


Figure 11: Streem Order

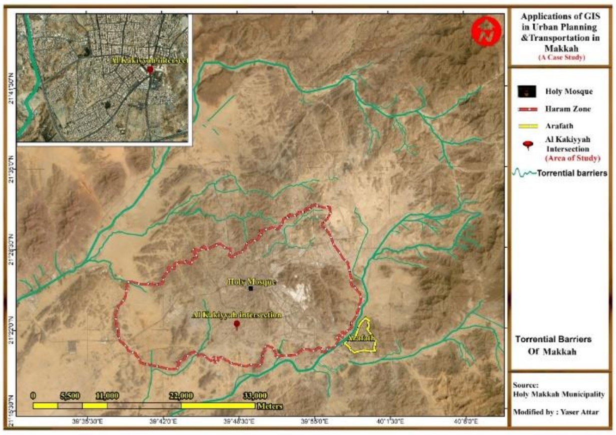


Figure 12: Torrential Barriers of Makkah

Figure 11 shows the streams order in the study area based on its topography, which is one of the main factors determining the transportation configuration system. But floods are another inhibiting factor in transportation despite general dryness. Al-Kakiyyah area is largely affected by the floods in the region. However, because of the importance of Makkah as the most important place in Islamic world, even with these natural difficulties that affect the roads network and the movement of transportation, this does not stop the urban development and the growth of this city. Saudi government and local agencies overcome these difficulties and utilize their capabilities, skills and financial investments to solve these challenges (Figure 12).

One the most important things that the government has done to reduce the dangers of streams is building a drainage network for streams, including the streams that had previously caused many disasters to Makkah. The last one happened in Ibrahim Valley, but did not enter the Holy Mosque at that time (Mirza and Baddin, 2001, p. 91).

Climate has an impact on roads network, transportation and economic, and on transportation network and traffic in the city. Even if it differs from one geographical region to another.

The effect of climate on planning in the study area is limited to the high temperatures factor in the roads network and transportation, and this does not mean that Makkah does not undergoes the influence of other factors such as coldness. But its effect remains less important compared to the high temperatures factor.

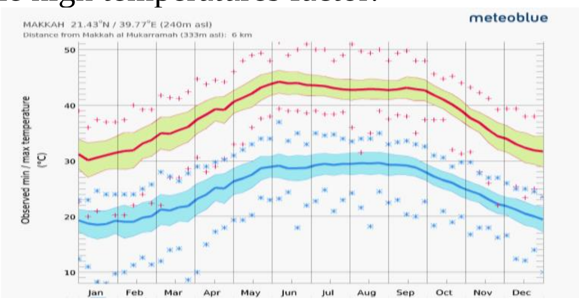


Figure 13: Last 12 months and 30 years climate (meteoblue)
Figure 13: Last 12 months and 30 years climate (meteoblue)

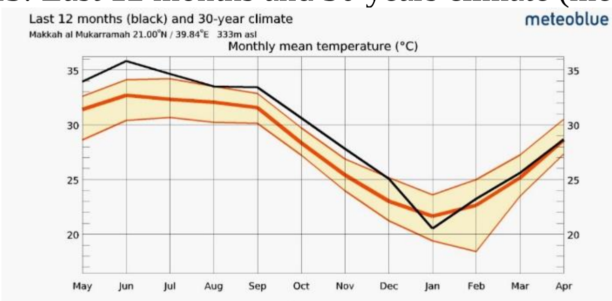


Figure 14: Temperature of Makkah (meteoblue)

High temperature can affect the movement of transportation through the section contact with roads of the tire’s rubber, since high temperature makes tires softer because they are made of rubber materials. High temperature also affects the vehicle's ability by reducing engine efficiency. Low temperature affects the water on the road surface, which increases the chances of slipping and accidents that will reduce traffic flow due to the limited speed. The temperature also affects the movement of pedestrians significantly during high and low temperature.

Figure 14 shows the effect of global warming and high temperatures in the study area. High temperature will affect the movement of vehicles in summer if the temperature still increasing in this way every year. On the other hand, the other months are not very different in temperatures; they are in the same range then the past 30 years.

2.3. Land use and urban growth

2.3.1 Land Use:

Although a variety of land uses in Makkah, 50 % of the area of the city is constituted of mountainous areas. Built-up areas represent 50% of open lands; residential areas are about 18% and the Holy Sites (Mina, Muzdalifa and Arafat) are about 15% of land uses. About 20% of the houses in Makkah are less than 100 m2, and about 65% of the houses are between 100 to 200 m2. Furthermore, only 15% of houses are 400 m2 and more. Most families live in apartments and houses (about 65%) while about 13% live in old houses, and about 10% of families in villas (Source: ATLAS of the city of Makkah Al-Mukarammah and the Holy Sites, no date). The percentage of land uses in Makkah showing that the major is residential (81.78%), then public utilities (8.93%), then educational services (3.82%), entertainment services (3.56%), religion services (1.47%), health services (0.33%), government services (0.06%), others (0.05%) (Holy Makkah Municipality) (Figure 15).

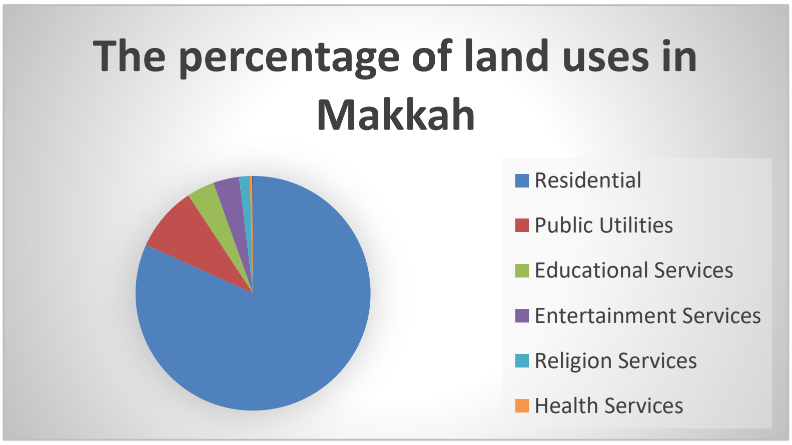


Figure 15 : Percentage of land use in Makkah
(source: Holy Makkah Municipality)

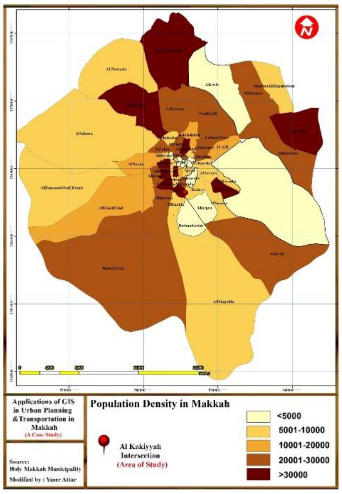


Figure 16: Popluation Density in Makkah

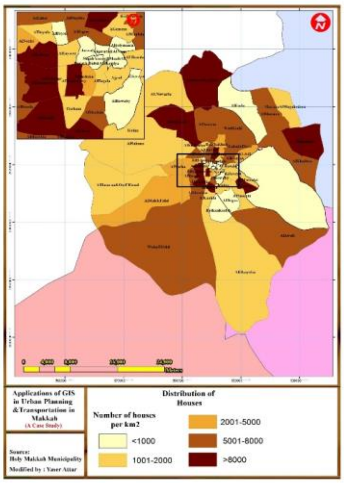


Figure 17: Distribution of Houses in Makkah

Land use is one of another important factors that affect the roads networks in cities. The area around Al-Kakiyyah intersection is one of the most active areas in Makkah. The region contains different categories of land uses such as commercial (showrooms, supermarkets and fish markets etc.), industrial (autocar workshops), public services (police, parks, social), health and residential services.

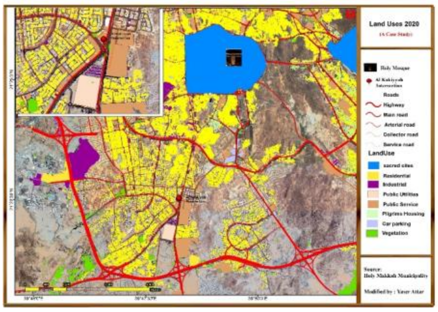


Figure 18 : Land Uses 2020

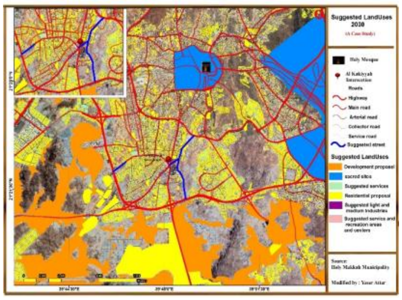


Figure 19 : Suggested Land Uses 2030

Figure 18 shows the diversity of the current land use categories, which affect significantly the road congestion. The major traffic congestion happens at the intersection of the main roads in the region at the times of going to work in the morning or leaving it depending on the workplaces and the work nature. The diversity of offered services requires the creation of alternative roads to reduce the present duration of traffic lights time to make traffic flow circulation easier

2.4. Transportation :

The main constraints and problems in transportation system can be resumed in the following highlighted points:

- Uncompleted ring roads and Limited public transportation system caused traffic jams on road network and corridors.
- Poor road network especially in the city center, which makes the cars movement difficult.
- The transportation system depends on small cars, which number increases 6.9% yearly. So, if this percentage keeps increasing with such rhythm, that means that by 1450H, the number of cars travels will increase in large proportion, which will cause traffic jams if no measures are taken to enhance public transportation system.

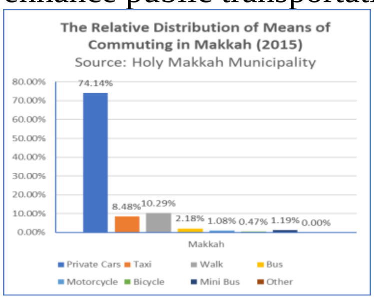


Figure 20: The Relative Distribution

Arrival road / Type of vehicle	Total الجملة النسبة Ratio	العدد Number	الشرائع Sharae'a	الجنوب South	المدينة Madinah	الطائف Taif	جدة /مكة Jeddah- Makkah القديم Old	السريع High way	طريق القدوم / نوع السيارة
Small	%48.5	14,141	3,495	1,354	2,659	1,612	115	4,906	صغيرة
Minivans	%15.9	4,641	1,480	372	735	886	45	1,123	صالون
Pick-up truck	%4.8	1,408	417	344	269	232	15	131	ونيت
Jeep	%12.5	3,657	1,034	753	689	699	32	450	جيب
Mini bus	%5.6	1,630	123	39	273	44	20	1,131	أتوبيس صغير
Bus	%12.4	3,611	1,081	314	797	0	52	1,367	أتوبيس كبير
Other	%0.3	81	21	1	24	19	1	15	أخرى
Total Number	%100	29,169	7,651	3,177	5,446	3,492	280	9,123	إجمالي العدد
Total Ratio		%100	%26.2	%10.9	%18.7	%12.0	%0.9	%31.3	إجمالي النسبة

Although Makkah has expanded in the last 40 years, there was no *master plan* for roads network and infrastructure which caused poor building and road networks. During the last two years, the city leaders have made an ambitious strategic plan for transportation to meet Vision 2030, but we think that this plan must be more realistic. In principle, Makkah transportation *master plan* should integrate the land uses and transportation, connect roads, reduce traffic jams, create transportation systems, and assure safety for the pedestrians.

2.5. Planning

The main constraints and problems in urban structure and functional composition can be resumed in the following highlighted points:

- The weak connection between the various parts of the city because of uncomplete ring roads which should disturb the vehicles movement.
- The survival of slums areas constitute a very important constraints in Makkah.
- The city center is suffering from missing the basics of urban rational planning.
- The heights system focused on the main road and corridors which caused neglecting the inner area.

From a historic point of view, Urban development of Makkah witnessed development and expansion periods and also periods of decrease summarized on the project of Makkah Guidance Plan until 2010 H by Holy Makkah Municipality and Ahmed Fared Mustafa (1434H).

The urban growth of Makkah has witnessed a noticeable increase since prophet Ibrahim (peace be upon him) came to Makkah regarding to the religious nature for all Muslims. We need to look at this development from a planning point of view and the impact of this on transportation networks and roads in the study area (Aljabiri, Nuzha Yaqzan, ٢٠١٣, p17).

Figure 21 and 22 show the following:

- Before 1925, the urban growth was around the Holy Mosque;
- The expansion in Makkah began significantly in 1971 when its area grew by more than 3 times compared to the previous period. The expansion of the circular shape of the city had increased significantly. This was due to the development in the construction processes, constructed facilities, services, hospitals and schools.
- Since 1981, construction requirements have been started in municipalities, due to the doubling of the area in the city, and it became a big city. This raised issues such as the area's efficiency in terms of housing, services, and trade. The number of pilgrims reached about 2 million (General Authority for Statistics) at that year, and this fact Influenced its urbanization and growth processes.
- During the period of 1992, the historical expansion of the Holy Mosque increased (The second Saudi expansion under King Fahd), which led increasing of the built-up area around the Holy Mosque. Tunnels, ring roads and corridors were created, and the urban growth appeared significantly in the city landscape.
- The period of 2001 was the period of relative urban stability, which did not witness the urban growth except in the southern parts of the city. Our study area was the most important area affected by that growth.
- The period after 2010 was a continuation period of the previous one. Construction began significantly in the southern and western areas and in the relatively high-altitude areas. This led to increase the

urban accumulation that started to appear in the study area. The increase of urbanization reached its natural extension and increased in the southern and eastern areas of the city. To manage planning in The Holy city, two main organizations are involved:

3. **Makkah Municipality** is one of the government departments responsible of developing the City of Makkah and its suburbs and urban planning, roads and lightening, and for improving humanization in the city in addition to managing necessary services to maintain the cleanliness and safe environment.

The Development Authority of Makkah Region (DAMR) **is involved in preparing and implementing and updating the master plans for the Central Region. But urban planning resorts external competences to plan the urban future expansion, manage the effects and demands of future urban development of Makkah with regards to the activities and population and work on a proactive methodology**

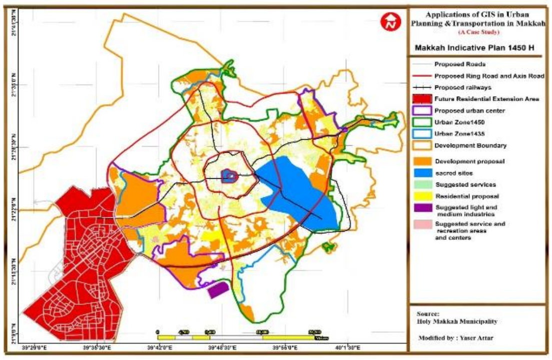


Figure 21: Makkah Indicative Plan

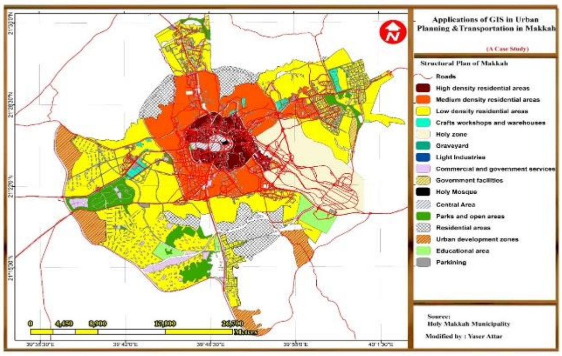


Figure 22: Structural plan of Makkah

The urban growth trends of the city indicate the impact of several factors that have positively and negatively affected the urban expansion of the city. But some directions have grown faster than others (Aljabiri, Nuzha Yaqzan, ٢٠١٣, p17).

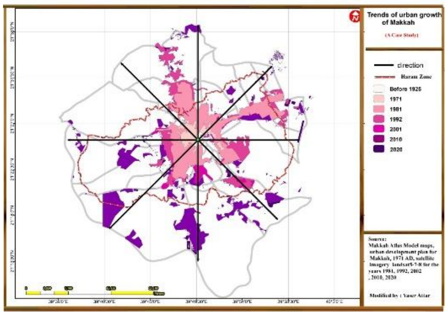


Figure 23 shows that the urban expansion of Makkah easily.

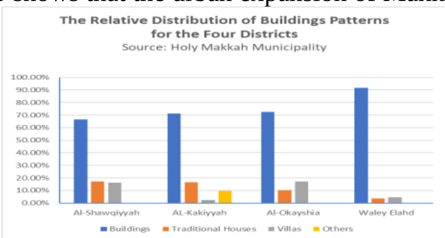


Figure 24: The Relative distribution of buildings patterns for the four districts (2015)

The main trends are: remarkable expansions in all directions the South-east direction toward Taif city, the fastest growing trend, with a huge urban leap after 1980; in the North-east direction because of applied plans for low-income people formed in some districts; in the South-west and North direction; in the South direction, because of dedicated local plans such as in Al-Oqaishiyy); in the West direction towards Jeddah road; in the North-west direction towards Al-Madinah Al-Munawwarah road. Only the east direction has stopped growing because reaching the boundaries of the holy places.

4-The case study of Al Kaakiyyah crossroads:

The main reason that justifies the choice of the first traffic intersection of (Al-Kakiyyah) and the urban area around it composed is the role it plays in Makkah transportation system and traffic. It is surrounded by the disctricts of Al-Shawqiyyah, AL-Kakiyyah, Al-Okayshia and Waley Elahd

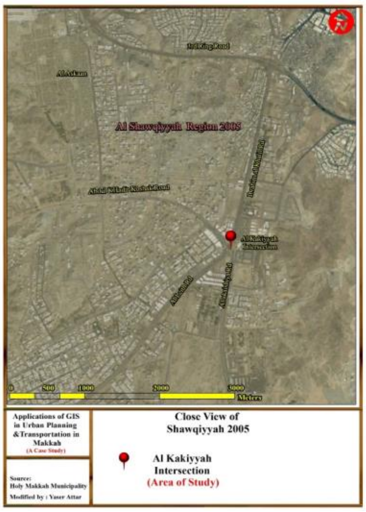


Figure 25 : Al-Shawqiyyah 2005

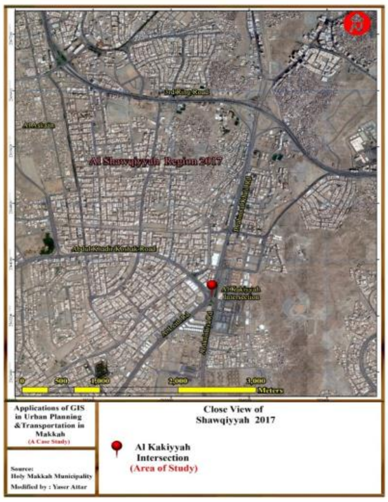


Figure 26 : Al-Shawqiyyah 2017

Figure 27 : Close View of Al-Kakiyyah Intersection

Figure 28 : 3D Model of the study area (Arc scene 10.7.1)

First, The authors will study the land uses and the comprehensive plan for Makkah (by The Holy Makkah Municipality and the one by Makkah Region Development Authority); then the authors will analyze the data, and finally, the authors will try to propose some solutions for the traffic jams in this area

4.1. Makkah Roads and the Road Case Study:

There are more than 2500 km roads in Makkah, which are divided into five types of roads:

- Highways: about 498 km, 19.61%
- Main roads: about 598 km, 23.59%

- Arterial roads: about 501 km, 19.74%
- Collector roads: about 681 km, 26.83%
- Service roads: about 260 km, 10.23Q%

The Holy Mosque is in the center. The roads start from the center to the outskirts of the city which take a ray shape, and Four Ring Roads link these main roads. In addition, the highways connect Makkah to other cities such as Jeddah, Madinah, Taif and Leith.

Al-Kakiyyah intersection is one of the most important intersections in Makkah as it links three roads together (Ibrahim Al- Khalil, Abdulqadir Koshak, and Leith Road) into 4 lanes

Figure 29 : Types of Roads

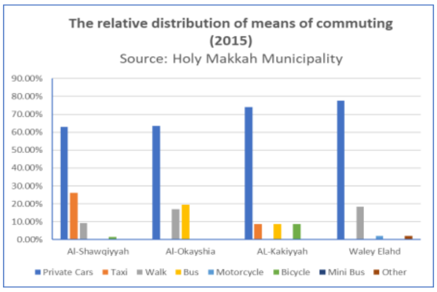


Figure 30 : The relative distribution of means of commuting which are used during the trip from home to work for the 4 districts (2015)

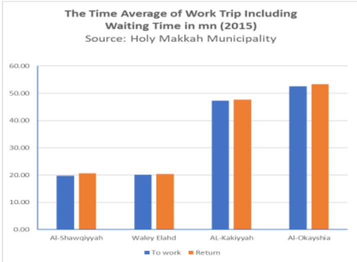


Figure 31: Trip including waiting time for the 4 Districts (2015)

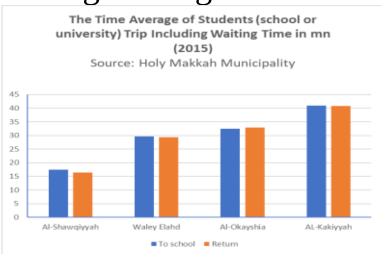


Figure 32: The relative distribution of buildings patterns for the f4 districts (2015)

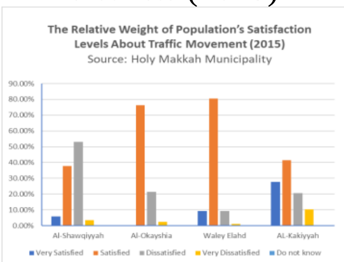


Figure 33: The relative weight of population's satisfaction levels about traffic movement for the 4 districts (2015)

By studying the Suggested Land Uses 2030 (figure 3.7.5), it appears that many areas around the study area are used as developmental and service areas, which will increase the intensity of the pressure on the roads. Therefore, the authors suggest the creation of a new road on the eastern side with the longitudinal extension as shown on figure (3.8.9). The authors think this road will help reducing the pressure on the roads network in the study area and facilitate reaching the final destinations by travelers and road users.

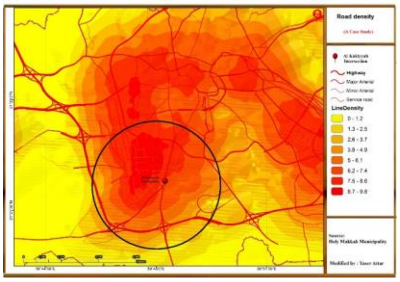


Figure 34 : Road Density

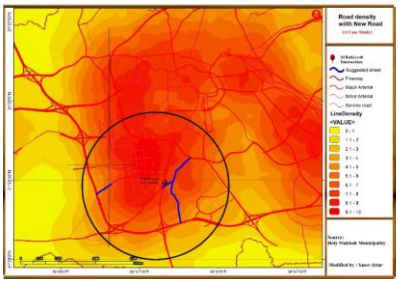


Figure 35 : Road Density with Suggested Roads

The study of the road density using the Line Density algorithm in ArcGIS shows that the intense pressure happens in the study area, while there is no big pressure in the eastern side of it; this is due to the lack of a developed roads network in it.

Figure 34 which was obtained by simulation, shows that the proposed road should reduce the pressure on the roads network on the main network. To complete Abdul Kadir Koshak Road (from the western side) and link it with the fourth ring road, and in order to reduce movement on the intersection in the study area, the authors propose another shorter road located at the west. Surely, it will reduce the movement of traffic coming from Jeddah or Al-Madinah roads, and those entering from the neighborhoods to the intersection, instead of forcing vehicles to use Al-Laith intersection by using the fourth ring road. The vehicles will move toward the traffic light in the study area.

In addition, the proposed intersection will reduce the residents' movement in case they want to go to Jeddah or Al-Medina roads, or to use the fourth ring road (north or south). This will create another entrance and exit to the area instead of entering and exiting from the traffic light in the whole study area.

Directions	Green time	Yellow time	Red time	Total time
East	54	3	3	60
North	69	3	3	75
South	39	3	3	45
				180

4.2 Traffic volume counts and rush hours:

The traffic count is undertaken manually at three-time frames. The first-time frame is at 6 am to 9 am; the second time frame is at 12 pm to 3 pm; and the third time frame is at 5 pm to 8 pm. From the results of these time frames, the rush hours are from 5 pm to 6 pm.

4.3. Traffic light:

The software “SYNCHRO” was used to (by Holy Makkah Municipality -Transportation and Traffic Department, special for my case study) analyze the current traffic light timing and know the time delay and the level of service. After measuring the green, yellow, and red-light times for each direction and the total time for their cycles at rush hour, the total length was 180 sec. as shown in the table below

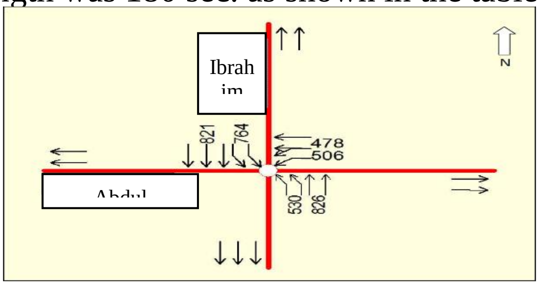


Figure 36: Traffic Volume Counts in Al-Kakiyyah Intersection at rush hour (17:00 to 18:00)

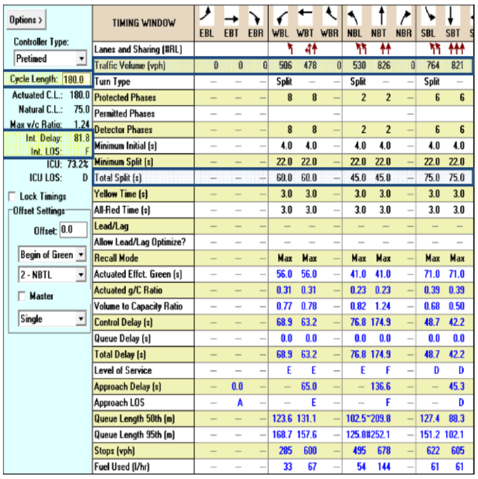
Table 3 : Time Delay Currently

(source: Holy Makkah Municipality)

The delay time is 81.8 sec., and the level of service is at level “F” based on the manual of managerial and technical requirements of traffic engineering. Based on the table, the north direction is the highest on traffic density which is 42% for cars going to Al Leith Road; then the east direction which is 33% for cars joining to Abdul Khadir Koshak Road; and finally, the south direction which is 25% for cars moving to Ibrahim Al Khaleel Road.

The authors focused on:

1- Total split (s): which shows the time delay for each direction.
2- Approach LOS: which shows the level of service for each direction.
3- Cycle Length: which shows the total time for the cycle.
4- Int Delay and Int LOS: which shows the average of time delay and the level of service for the traffic light.



TIMING WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT
Lanes and Sharing (#RL)											
Traffic Volume (vph)	0	0	0	506	478	0	530	826	0	764	821
Turn Type	–	–	–	Split	–	–	Split	–	–	Split	–
Protected Phases	–	–	–	8	8	–	2	2	–	6	6
Permitted Phases	–	–	–			–			–		
Detector Phases	–	–	–	8	8	–	2	2	–	6	6
Minimum Initial (s)	–	–	–	4.0	4.0	–	4.0	4.0	–	4.0	4.0
Minimum Split (s)	–	–	–	22.0	22.0	–	22.0	22.0	–	22.0	22.0
Total Split (s)	–	–	–	60.0	60.0	–	45.0	45.0	–	75.0	75.0
Yellow Time (s)	–	–	–	3.0	3.0	–	3.0	3.0	–	3.0	3.0
All-Red Time (s)	–	–	–	3.0	3.0	–	3.0	3.0	–	3.0	3.0
Lead/Lag	–	–	–	–	–	–	–	–	–	–	–
Allow Lead/Lag Optimize?	–	–	–	–	–	–	–	–	–	–	–
Recall Mode	–	–	–	Max	Max	–	Max	Max	–	Max	Max
Actuated Effct. Green (s)	–	–	–	56.0	56.0	–	41.0	41.0	–	71.0	71.0
Actuated g/C Ratio	–	–	–	0.31	0.31	–	0.23	0.23	–	0.39	0.39
Volume to Capacity Ratio	–	–	–	0.77	0.78	–	0.82	1.24	–	0.68	0.50
Control Delay (s)	–	–	–	68.9	63.2	–	76.8	174.9	–	48.7	42.2
Queue Delay (s)	–	–	–	0.0	0.0	–	0.0	0.0	–	0.0	0.0
Total Delay (s)	–	–	–	68.9	63.2	–	76.8	174.9	–	48.7	42.2
Level of Service	–	–	–	E	E	–	E	F	–	D	D
Approach Delay (s)	–	0.0	–	–	65.0	–	–	136.6	–	–	45.3
Approach LOS	–	A	–	–	E	–	–	F	–	–	D
Queue Length 50th (m)	–	–	–	123.6	131.1	–	102.5	~209.8	–	127.4	88.3
Queue Length 95th (m)	–	–	–	168.7	157.6	–	125.8	#252.1	–	151.2	102.1
Stops (vph)	–	–	–	285	600	–	495	678	–	622	605
Fuel Used (l/hr)	–	–	–	33	67	–	54	144	–	61	61

Figure 37: Results of The Current Situation at rush hour (17:00 to 18:00) by the software “SYNCHRO”.

Table 4: The Standard of the Level of Service for Signalized Intersection

Level of Service (LOS)	**Flow**	**Delay time (second/ vehicle)**
A	free flow	≥ 10
B	reasonably free flow	> 10 – 20
C	stable flow	> 20 – 35
D	approaching unstable flow	> 35 – 55
E	unstable flow	> 55 – 80
F	forced or breakdown flow	> 80

Level of service (LOS) is a quantitative stratification of quality of service into six letter grade levels used to relate the quality of motor vehicle traffic service. LOS is an engineering technique to address and analyze roadways and intersections by categorizing traffic flow based on many factors like vehicle speed, density, congestion, etc.

Since the traffic light in this intersection is the first traffic light that travelers face when they come to Makkah or from the 4th Ring Road, the city planners did not come up with solutions to remove this traffic light. They preferred to keep the traffic light technique mean to control the flow of traffic to the Holy Mosque. This is because that on the one hand, it is difficult to make a bridge to solve the problem in this intersection. On the other hand, it is difficult to propose underground solutions since there is a complex network of utilities. So, the short-term solution is to reset the traffic light timing to improve the level of service. However, traffic volume counts have been added to the system to get the best timing at rush hours and level of service to a “C” level and the delay time to 34 sec.

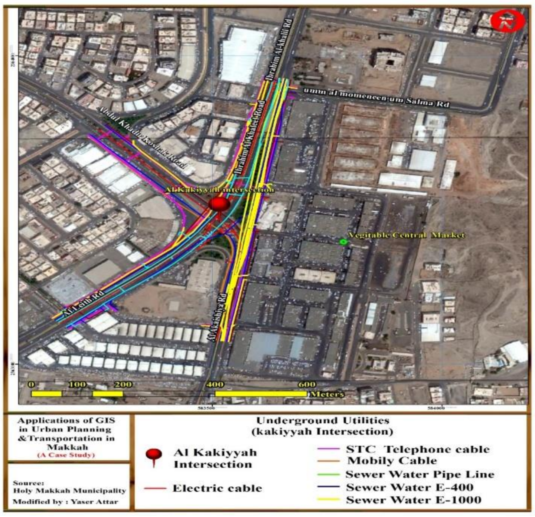


Figure 38: Underground Utilities

4.4 Morning Rush Hour (8:00 to 9:00):

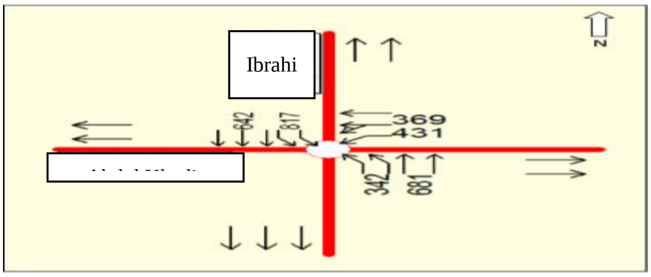
“SYNCHRO” was used to improve the timing delay in the case study. After measuring the green, yellow, and red-light times for each direction and the total time for their cycles at morning rush hour, the total length was 70 sec. as shown in the table 5:

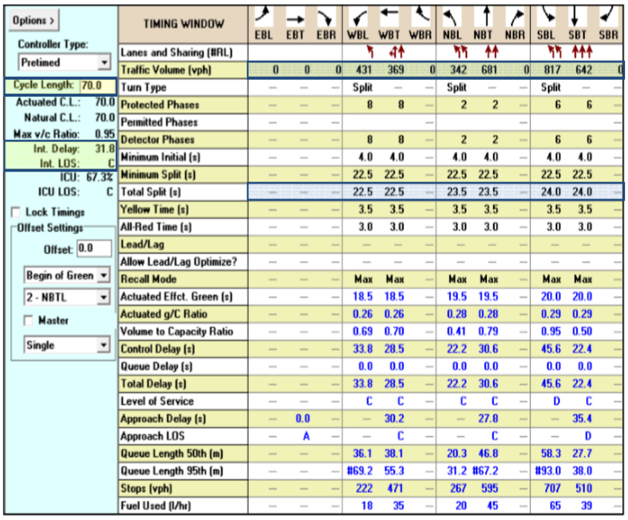
Table 5: Time Delay for Morning
Rush Hours (suggested)

Directions	Green time	Yellow time	Red time	Total time
East	17	3	3	23
North	18	3	3	24
South	17	3	3	23
				70

The delay time is 31.8 sec., and the level of service is at level "C". Based on the table, the north direction is the highest on traffic density which is 34% for cars going to Al Leith Road, then the east direction which is 33% for cars joining to Abdul Khadir Koshak Road, and finally, the south direction which is 33% for cars moving to Ibrahim Al Khaleel Road.

Figure 39 Suggested timing and the total time
for the cycle at rush hour (8:00 to 9:00)





Options ›	TIMING WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Controller Type: Pretimed	Lanes and Sharing (#RL)												
	Traffic Volume (vph)	0	0	0	431	369	0	342	681	0	817	642	0
Cycle Length: 70.0	Turn Type	—	—	—	Split	—	—	Split	—	—	Split	—	—
Actuated C.L.: 70.0	Protected Phases	—	—	—	8	8	—	2	2	—	6	6	—
Natural C.L.: 70.0	Permitted Phases	—	—	—			—			—			—
Max v/c Ratio: 0.95	Detector Phases	—	—	—	8	8	—	2	2	—	6	6	—
Int. Delay: 31.8	Minimum Initial (s)	—	—	—	4.0	4.0	—	4.0	4.0	—	4.0	4.0	—
Int. LOS: C	Minimum Split (s)	—	—	—	22.5	22.5	—	22.5	22.5	—	22.5	22.5	—
ICU: 67.3%	Total Split (s)	—	—	—	22.5	22.5	—	23.5	23.5	—	24.0	24.0	—
ICU LOS: C	Yellow Time (s)	—	—	—	3.5	3.5	—	3.5	3.5	—	3.5	3.5	—
Lock Timings	All-Red Time (s)	—	—	—	3.0	3.0	—	3.0	3.0	—	3.0	3.0	—
Offset Settings	Lead/Lag	—	—	—	—	—	—	—	—	—	—	—	—
Offset: 0.0	Allow Lead/Lag Optimize?	—	—	—	—	—	—	—	—	—	—	—	—
Begin of Green	Recall Mode	—	—	—	Max	Max	—	Max	Max	—	Max	Max	—
2 - NBTL	Actuated Effct. Green (s)	—	—	—	18.5	18.5	—	19.5	19.5	—	20.0	20.0	—
Master	Actuated g/C Ratio	—	—	—	0.26	0.26	—	0.28	0.28	—	0.29	0.29	—
Single	Volume to Capacity Ratio	—	—	—	0.69	0.70	—	0.41	0.79	—	0.95	0.50	—
	Control Delay (s)	—	—	—	33.8	28.5	—	22.2	30.6	—	45.6	22.4	—
	Queue Delay (s)	—	—	—	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—
	Total Delay (s)	—	—	—	33.8	28.5	—	22.2	30.6	—	45.6	22.4	—
	Level of Service	—	—	—	C	C	—	C	C	—	D	C	—
	Approach Delay (s)	—	0.0	—	—	30.2	—	—	27.8	—	—	35.4	—
	Approach LOS	—	A	—	—	C	—	—	C	—	—	D	—
	Queue Length 50th (m)	—	—	—	36.1	38.1	—	20.3	46.8	—	58.3	27.7	—
	Queue Length 95th (m)	—	—	—	#69.2	55.3	—	31.2	#67.2	—	#93.0	38.0	—
	Stops (vph)	—	—	—	222	471	—	267	595	—	707	510	—
	Fuel Used (l/hr)	—	—	—	18	35	—	20	45	—	65	39	—

Table : Traffic Volume Counts at rush hour (8:00 to 9:00) (suggested)

Based on the above figure:

1- Total split (s): has been improved.
2- Approach LOS: has been improved.
3- Cycle Length: has been improved.
4- Int Delay and Int LOS: has been improved.

4.5 Afternoon Rush Hour (13:15 to 14:15):

After measuring the green, yellow, and red-light times for each direction and the total time for their cycles at morning rush hour, the total length was 70 sec. as shown in the table below:
The delay time is 31.8 sec., and the level of service is at level "C". Based on the table, the north direction is the highest on traffic density which is 34% for cars going to Al Leith Road; then the east direction which is 33% for cars joining to Abdul Khadir Koshak Road; and finally, the south direction which is 33% for cars moving to Ibrahim Al Khaleel Road

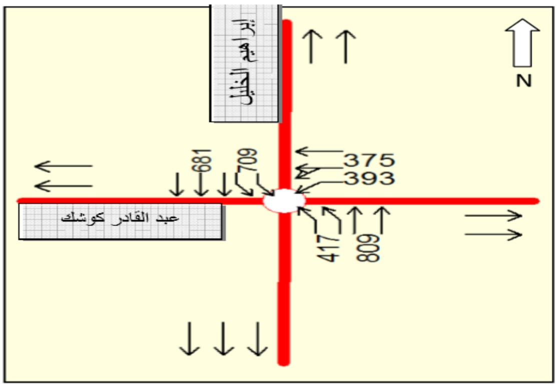
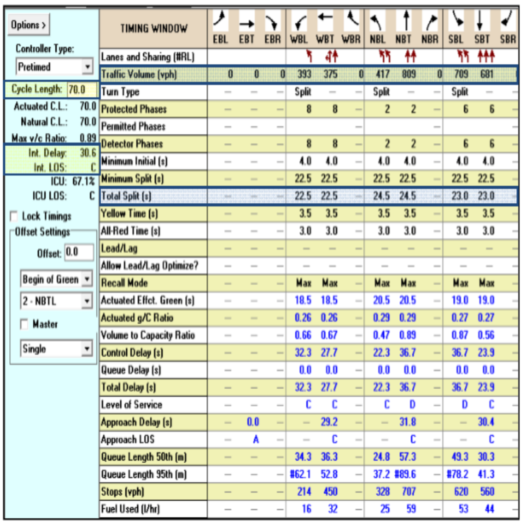


Table 6 : Time Delay for Afternoon Rush Houre (suggested)

Directions	Green time	Yellow time	Red time	Total time
East	17	3	3	23
North	18	3	3	24
South	17	3	3	23
				70



TIMING WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	0	0	0	393	375	0	417	809	0	709	681	[illegible]
Turn Type	–	–	–	Split	–	–	Split	–	–	Split	–	–
Protected Phases	–	–	–	8	8	–	2	2	–	6	6	–
Permitted Phases	–	–	–			–			–			–
Detector Phases	–	–	–	8	8	–	2	2	–	6	6	–
Minimum Initial (s)	–	–	–	4.0	4.0	–	4.0	4.0	–	4.0	4.0	–
Minimum Split (s)	–	–	–	22.5	22.5	–	22.5	22.5	–	22.5	22.5	–
Total Split (s)	–	–	–	22.5	22.5	–	24.5	24.5	–	23.0	23.0	–
Yellow Time (s)	–	–	–	3.5	3.5	–	3.5	3.5	–	3.5	3.5	–
All-Red Time (s)	–	–	–	3.0	3.0	–	3.0	3.0	–	3.0	3.0	–
Lead/Lag	–	–	–	–	–	–	–	–	–	–	–	–
Allow Lead/Lag Optimize?	–	–	–	–	–	–	–	–	–	–	–	–
Recall Mode	–	–	–	Max	Max	–	Max	Max	–	Max	Max	–
Actuated Effct. Green (s)	–	–	–	18.5	18.5	–	20.5	20.5	–	19.0	19.0	–
Actuated g/C Ratio	–	–	–	0.26	0.26	–	0.29	0.29	–	0.27	0.27	–
Volume to Capacity Ratio	–	–	–	0.66	0.67	–	0.47	0.89	–	0.87	0.56	–
Control Delay (s)	–	–	–	32.3	27.7	–	22.3	36.7	–	36.7	23.9	–
Queue Delay (s)	–	–	–	0.0	0.0	–	0.0	0.0	–	0.0	0.0	–
Total Delay (s)	–	–	–	32.3	27.7	–	22.3	36.7	–	36.7	23.9	–
Level of Service	–	–	–	C	C	–	C	D	–	D	C	–
Approach Delay (s)	–	0.0	–	–	29.2	–	–	31.8	–	–	30.4	–
Approach LOS	–	A	–	–	C	–	–	C	–	–	C	–
Queue Length 50th (m)	–	–	–	34.3	36.3	–	24.8	57.3	–	49.3	30.3	–
Queue Length 95th (m)	–	–	–	#62.1	52.8	–	37.2	#89.6	–	#78.2	41.3	–
Stops (vph)	–	–	–	214	450	–	328	707	–	620	560	–
Fuel Used (l/hr)	–	–	–	16	32	–	25	59	–	53	44	–

Table 8: Suggested timing and the total tme for the cycle at the rush hour (13:15 to 14:15)

Figure 41

Directions	Green time	Yellow time	Red time	Total time
East	17	3	3	23
North	20	3	3	26
South	20	3	3	26
				75

Based on the above figure:

1- Total split (s): has been improved.
2- Approach LOS: has been improved.
3- Cycle Length: has been improved.
4- Int Delay and Int LOS: has been improved.
5-

4.6 Evening Rush Hour (17:00 to 18:00):

After measuring the green, yellow, and red-light times for each direction and the total time_for their cycles at morning rush hour, the total length was 70 sec. as shown in the table below:

The delay time is 34.6 sec., and the level of service is at level “C”. Based on the table, the north direction is the highest on traffic density which is 34.6 % for cars going to Al Leith Road, then, the south direction which is 34.6 % for cars joining to Ibrahim Al Khaleel Road, and finally the east direction which is 30.8% for cars moving to Abdul Khadir Koshak Road.

Options >
Controller Type: Pretimed
Cycle Length: 75.0
Actuated C.L.: 75.0
Natural C.L.: 70.0
Max v/c Ratio: 0.89
Int. Delay: 34.6
Int. LOS: C
ICU: 73.2%
ICU LOS: D
Lock Timings
Offset Settings
Offset: 0.0
Begin of Green
2 - NBTL
Master
Single

TIMING WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	0	0	0	506	478	0	530	826	0	764	821	0
Turn Type	–	–	–	Split	–	–	Split	–	–	Split	–	–
Protected Phases	–	–	–	8	8	–	2	2	–	6	6	–
Permitted Phases	–	–	–			–			–			–
Detector Phases	–	–	–	8	8	–	2	2	–	6	6	–
Minimum Initial (s)	–	–	–	4.0	4.0	–	4.0	4.0	–	4.0	4.0	–
Minimum Split (s)	–	–	–	22.5	22.5	–	22.5	22.5	–	22.5	22.5	–
Total Split (s)	–	–	–	23.0	23.0	–	26.0	26.0	–	26.0	26.0	–
Yellow Time (s)	–	–	–	3.5	3.5	–	3.5	3.5	–	3.5	3.5	–
All-Red Time (s)	–	–	–	3.0	3.0	–	3.0	3.0	–	3.0	3.0	–
Lead/Lag	–	–	–	–	–	–	–	–	–	–	–	–
Allow Lead/Lag Optimize?	–	–	–	–	–	–	–	–	–	–	–	–
Recall Mode	–	–	–	Max	Max	–	Max	Max	–	Max	Max	–
Actuated Effct. Green (s)	–	–	–	19.0	19.0	–	22.0	22.0	–	22.0	22.0	–
Actuated g/C Ratio	–	–	–	0.25	0.25	–	0.29	0.29	–	0.29	0.29	–
Volume to Capacity Ratio	–	–	–	0.87	0.88	–	0.59	0.89	–	0.85	0.61	–
Control Delay (s)	–	–	–	51.2	41.1	–	25.6	38.1	–	34.9	25.0	–
Queue Delay (s)	–	–	–	0.0	0.0	–	0.0	0.0	–	0.0	0.0	–
Total Delay (s)	–	–	–	51.2	41.1	–	25.6	38.1	–	34.9	25.0	–
Level of Service	–	–	–	D	D	–	C	D	–	C	C	–
Approach Delay (s)	–	0.0	–	–	44.3	–	–	33.2	–	–	29.8	–
Approach LOS	–	A	–	–	D	–	–	C	–	–	C	–
Queue Length 50th (m)	–	–	–	51.3	54.1	–	35.6	63.4	–	56.4	39.5	–
Queue Length 95th (m)	–	–	–	#99.7	#85.2	–	50.7	#96.4	–	#85.3	52.0	–
Stops (vph)	–	–	–	272	591	–	434	726	–	670	677	–
Fuel Used (l/hr)	–	–	–	25	49	–	32	59	–	54	51	–

Table 9: Traffic Volume Counts at rush hour (17:00 to 18:00) (suggested)

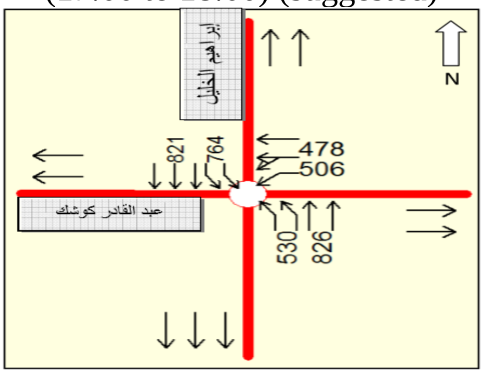


Figure 4.3.2 Suggested timing and the total time for the cycle at rush hour (17:00 to 18:00

Based on the above figure:
1- Total split (s): has been improved.
2- Approach LOS: has been improved.
3- Cycle Length: has been improved.
4- Int Delay and Int LOS: has been improve

5.Conclusion and future work

The research relates closely to the Holy Makkah Municipality work. It consisted in uploading GIS plans, establishing base maps, and tried to take advantage of these documents in city planning and transportation. The goal is to make the transport network more efficient and integrated with land uses and to provide for the relevant authorities to get benefit of this work.

The city of Makkah is very old and has a lot of mountains, which caused problems for planners and decision-makers in city planning, especially because of the urban expanding and rapid development in the region. These aspects caused more slums and numerous difficulties for the transport networks; they were analyzed in this research supported by various maps and software outputs.

In this study The authors focused on congestion in roads network and intersections, but The authors noticed problems also during the low level of service, the lack or the deficiencies of public transportation that affect visitors, and pilgrims.

The authors tried also to demonstrate that GISs should be one of the most important and useful tools that will help planners in improving urban planning and transport. They can be integrated with planning programs and help to obtain short-term and long-term solutions, as The authors did in the case study of this research. The chosen example of Al Kakiyyah intersection was chosen as a case study to improve traffic movement.

Therefore, specialists may consider this work to re-planning the city by using modern technology, systems and modern architectural concepts and integrate them to the transport networks. This may contribute meeting Saudi Vision 2030 goals for Makkah and help the growing number of visitors and pilgrims.

This research has shown how a GIS was used to improve the planning of the case study and minimizing the delay time and how this GIS can be an important tool in urban planning and transportation.

Serval future works could be achieved by using GIS, so The authors intend further to integrate the infrastructure and new projects in the city to get better results and with less cost. In addition, The authors will study how the new projects can affect the city and the network.

Bibliography:

1- Abdulrahman, Manal A. (2011). Spatial analysis of empty land in Makkah Al-Mukarramah using GIS.

2- Abu Dhabi Urban Planning Council (no date). “Abu Dhabi Urban Street Design Manual” 1.0 Edition. Abu Dhabi Urban Planning Council.

3- Al-Ahmadia K, Heppenstall A, See L, and Hogg J (2008). Modeling urban growth dynamics using cellular automata and GIS, Proceedings of the Third National GIS Symposium in Saudi Arabia, April 7 – 9, Al-Khobar, Saudi Arabia.

4- Al-Aqeel, Abdullah M. (2014). “Science and Technology”. Journal of King Abdulaziz City for Science and Technology vol 111.

5- Al-Asqa, Amna bint Abdulrahman (2018). “The role of geographic information systems in handling traffic accidents”, An applied study on Eastern Riyadh Road. The “12” GIS Symposium in Saudi Arabia.

6- Al-Gamdi, Saad Abo Ras (2006). Change Detection Using Digital Satellite Data Case study: The Holly City of Makkah and its Surroundings.

7- Al-Ghamdi K, Elzahrany R, Mirza M, and Dawod G (2012). Impacts of urban growth on flood hazards in Makkah City, Saudi Arabia.

8- Al-Qurashi A and Kumar L (2014). Land Use and Land Cover Change Detection in the Saudi Arabian Desert Cities of Makkah and Al-Taif Using Satellite Data.

9- Al-Jabri, Nuzha Y. (2013) .Mechanisms of Urban Growth of Makkah Al-Mukarramah.

10- Al-Joufie, Mohammed O. (2012). “Urban Growth and Transport in Jeddah”. University of Twente.

11- Al-Shehri, Noura Saad (2013). The effect of the topographical factor on the urban growth of the city of Makkah Al-Mukarramah, using the techniques of geographical information systems and remote sensing.

12- Ali M, Khan S, Aslam The authors and Khan Z (2011). Simulation of the impacts of land-use change on surface runoff of Lai Nullah Basin in Islamabad, Pakistan, Landscape and Urban Planning. 102: 271-279.

13- Alkhaldy, Ibrahim (2009). “Acritical Spatial Analysis of Residential Planning in Makkah, Saudi Arabia”. Marshall University

14- Alshalalfah B, Shalaby A, Dale S and Othman F (2015). “Feasibility Study of Aerial Ropeway Transit in the Holy City of Makkah”. Transportation Planning and Technology.

15- Amirahmadi H and Elshakhs S (1993). “Urban development in the Muslim world”. Chapter 3 Planning and Development in Makkah (Nohad A. Toulan). New Brunswick, N.J: Center for Urban Policy Research.

16- Aziz M and Al-Zaher A (2002). “Spatial analysis for urban transportation network in Kuwait City”. Kuwait University.

17- Barker, Kate (2006).” Barker Review of Land Use Planning: Final Report, Recommendations”. Stationery Office Books (TSO).

18- beingness (2013). “Comprehensive Plan for Public Transportation in Makkah and Holy Sites” final report. Development Authority of Makkah and Holy Sites.

19- Brail, Richard K. (2008). “Planning support systems for cities and regions”. The Lincoln Institute of Land Policy.

20- bw. engineers (2013). “Comprehensive Plan for Transportation and traffic in Makkah” Holy Makkah Municipality.

21- Campagna, M. (2006). “GIS for sustainable development.” In GIS for sustainable development, ed. Michele Campagna, 320-. Boca Raton, Florida: CRC Press.

22- Dawod, G. and MOHAMMED, W. (2009). Data management of different height systems within GPS/GIS integrated spatial technology¸ Middle East Spatial Technology Conference (MEST2009) ¸ December 7-9¸ Kingdom of Bahrain.

23- Department for Communities and Local Government (2009). “Planning for Town Centers”. Communities and Local Government, London.
24- Department for Transport (2004).” TECHNICAL GUIDANCE ON ACCESSIBILITY PLANNING IN LOCAL TRANSPORT PLANS”. The Department for Transport is a UK Government department.
25- Development Authority of Makkah and Holy Sites (no date). “Development Plan for Holy Sites”. Development Authority of Makkah and Holy Sites.
26- Feng, L. (2009). Applying remote sensing and GIS on monitoring and measuring urban sprawl. A case study of China, Revista Internacional de Sostenibilisas, Tecnologia y Humanismo, (4) 47-56.
27- General Authority for Statistics (2016). “Hajj Statistics 1437”. General Authority for Statistics.
28- Geomatika Consultancy Bureau (no date). “ATLAS of the City of Makkah Al-Mukarammah and the Holy Sites”. Holy Makkah Municipality.
29- GIS department (no date). “Dictionary of Geographic data for SDI project”. Holy Makkah Municipality.
30- Grant, Jill (2006). The good community: new urbanism in theory and practice Planning.
31- Holy Makkah Municipality (2015). “Tameer”. Journal of Holy Makkah Municipality Vol 1.
32- Koshak, Nabeel A. (2006). Developing a Web-Based GIS for Hajj Traffic Plan (HajjGIS.Net).
33- Longley P, Goodchild M, Maguire D and Rhind D (2005). “Geographical Information Systems: Principles, Techniques, Management and Applications (Abridged Edition)”. Chapter 59 Transportation GIS (N. M. WATERS), Chapter 62 Urban planning and GIS (A G-O YEH). John Wiley & Sons, Inc.: Hoboken, NJ.
34- Miller H, Shaw S-L (2001). “Geographic Information Systems for Transportation: Principles and Applications”. New York: Oxford University Press.
35- Ministry of municipal and rural affairs (2016). “Studying administrative and technical requirements for traffic engineering”. Ministry of municipal and rural affairs.

36- Mirza M¸ Dawod G and Al-Ghamdi K (2011). Accuracy and relevance of digital elevation models for geomatics applications – A case study of Makkah municipality¸ Saudi Arabia¸ International Journal of Geomatics and Geosciences¸ V.1¸ No. 4¸ pp. 803-812.
37- Murad, Abdulkader A. (2007). Creating a GIS application for local health care planning in Saudi Arabia.
38- Saudi Vision 2030 (2016). www.vision2030.gov.sa
39- Shaw S-L and Xin X (2003). "Integrated land use and transportation interaction: a temporal GIS exploratory data analysis approach". Journal of Transport Geography 11 (2003) 103–115
40- Subash Chandra.M, Rajalakshmi.S, Rajakumari and Madhavan. K.D (2008). "GIS Applications in Urban Planning". Sathyabama University, Jeppiaar Nagar, Chennai, India.
41- Ta'ani, Ayman (2013). A Remote Sensing and GIS Evaluation of Urban Expansion in Al- Hufof, Saudi Arabia.
42- Tomlinson, Roger F. (2003). Thinking About GIS: Geographic Information System Planning for Managers. Environmental Systems Research Institute, Inc., Redlands, CA, USA.
43- UN-Habitat (2013). "Urban Planning for City Leaders – A handbook". 2nd Edition, Reprinted December 2013. United Nations Human Settlements Programme (UN-Habitat).
44- US Department of Transportation (2004). "Signalized Intersections Informational Guide". 2nd Edition, July 2013. Federal Highway Administration (FHWA), WASHINGTON, DC
45- Zuhair Fayez Partnership Consultants (2004). "Updating the Structure Plan of Makkah 1450 H" final report. Development Authority of Makkah Region.

المستلخص

تتمتع مكة باحترام وقيمة فريدة في العالم الإسلامي. حيث يستقبل المسجد الحرام كل عام ملايين الزوار من الحجاج والمعتمرين من جميع أنحاء العالم وهذا العدد في تزايد مستمر. كما تتزايد الكثافة السكانية العالية أيضًا على الرغم من المعوقات الطبوغرافية والمناخية. وتتسبب هذه الزيادة في أعداد الحجاج والمعتمرين من حين لآخر وحركتهم المستمرة في ازدحام مروري كبير في العديد من الأماكن. وكان توسع ضواحي الحرم الشريف وزيادة كثافة السكان في المنطقة المركزية وشبكة النقل من المنطقة المركزية هي الاستجابات التخطيطية الرئيسية لهذه القضية الحاسمة. لكنها كشفت أيضا عن عدم كفاءتها لحل جذري لمشكلة الوصول للحرم الشريف ووسط المدينة.

يهتم المؤلفون في هذا البحث بدراسة حالة تقاطع الكعكية، أحد أكثر الأماكن ازدحامًا في مكة المكرمة. والبحث يهدف إلى تحسين انسياب حركة المرور على الطرق من وإلى المسجد الحرام والأماكن الأخرى باستخدام هذا التقاطع المحوري المركزي. كما تم إجراؤه على عدة خطوات: جمع البيانات وترتيبها (بيانات النقل والخرائط وإحصاءات المستخدمين والدراسات والأعمال المنشورة عن مكة المكرمة وشبكتها)؛ دراسة الوضع الحالي لمدينة مكة المكرمة وتقاطع الكعكية، وتنفيذ سيناريو المحاكاة لقياس مدى تحسين المرور في هذا المكان.

تمخضت نتائج الدراسة أن التغييرات الجذرية هي التي تحسن من سيولة حركة المرور، خاصة خلال ساعات الذروة. بالطبع، يجب أن تكون الحلول على المدى الطويل شاملة وتتضمن تعديلات جذرية في استخدام الأراضي ومسارات الطرق وشبكة النقل وإدارتها، ولكن على المدى القصير، قد يؤدي تعزيز التفكير ثانية وإعادة تصميم الأماكن عن طريق استخدام البرامج المخصصة إلى تحسين التخطيط الحضري وحركة النقل.

الكلمات المفتاحية: نظم المعلومات الجغرافية، التخطيط العمراني، النقل، مكة المكرمة، تقاطع الكعكية.