TRANSPORT MODELING IN MAKKAH: CHALLENGES AND APPROACHES

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Abstract

This paper describes a traffic and transport analysis undertaken for the western area of Makkah, Saudi Arabia. The analysis includes the modeling of existing and projected traffic conditions in the area, as well as an assessment of the impact of future developments, including the Makkah Western Gateway, a newly proposed transportation corridor.

As a tool for the analysis, a traffic model was needed for the western and central portion of the city. The data available for the construction of the model was limited, however, consisting primarily of traffic counts at selected locations during normal and religious peak periods (Ramadan and the Hajj pilgrimage). Other data, such as socioeconomic data and origin-destination studies, were not readily available. Furthermore, due to the unique religious and cultural characteristics of Makkah, models based on data from other cities were not deemed to be appropriate.

Faced with such challenges, alternative approaches were developed and applied in the development of the transport model, including a capacity-based mode split analysis. This paper presents the modeling methodology, focusing on the practical difficulties encountered and the approaches used to overcome them, as well as results and findings from the study.

Keywords: Makkah; Mecca; Saudi Arabia; Traffic modeling; Demand; Mode split
Topic Area: G07 Case studies

1. Introduction

The city of Makkah, located in western Saudi Arabia, is the most sacred of the Muslim cities and is the religious and spiritual center of Islam. During the holy periods of Ramadan and Hajj, Makkah experiences a large influx of visitors and pilgrims. As a result, travel demand during these two peak seasons goes up significantly, leading to major congestion on the transportation network. This demand is expected to grow considerably in the future, with the number of Hajj pilgrims, for example, increasing from 2 million currently to 4.8 million within the next 50 years (MCDC, 2002). Currently, 60% of the traffic coming into Makkah enters via the western entrance to the city, as most visitors arrive via the international airport in Jeddah, to the west.

In order to handle the projected future demand and to improve access to the city from the west, a new western transportation corridor is envisioned for Makkah. As a tool for the analysis of the transportation network, including the potential impact of the new Makkah Western Gateway (MWG), a traffic model was needed for the western and central portion of the city. The intent of this model was to provide a high-level model of traffic in Makkah to assist in quantifying the impacts of the MWG and in identifying areas of concern for further study. The study also considered multimodal demand, including pedestrians and transit.

This paper describes the process by which an analysis of the western area of Makkah was performed. The analysis included the modeling of existing and projected traffic conditions in the area, as well as an assessment of the impact of future developments, including the proposed Makkah Western Gateway. The structure of this paper is as follows:

- Section 2 provides background information on Makkah and the proposed Makkah Western Gateway project;
- Section 3 describes the data sources available for the modeling work;
- Section 4 details the modeling methodology;
- Section 5 describes the scenarios evaluated with the model;
- Section 6 presents the modeling results; and
- Section 7 presents conclusions from the study.

2. Background

2.1 Makkah's road network

Makkah's street network is arranged in a radial and ring road configuration, centered on the Haram, the holy mosque. The circulation system includes three levels of ring roads around the center of Makkah, as shown in Figure 1.

The First Ring Road is a peripheral main road that provides vehicular access to the Central Area via local roads. It diverts heavy traffic from the boundaries of the Haram and releases traffic congestion by providing peripheral outlets. For much of its length, the roadway is constructed underground to separate major pedestrian movements near the Haram from the interference of heavy traffic. The western section of the First Ring Road, currently incomplete, is planned for construction.

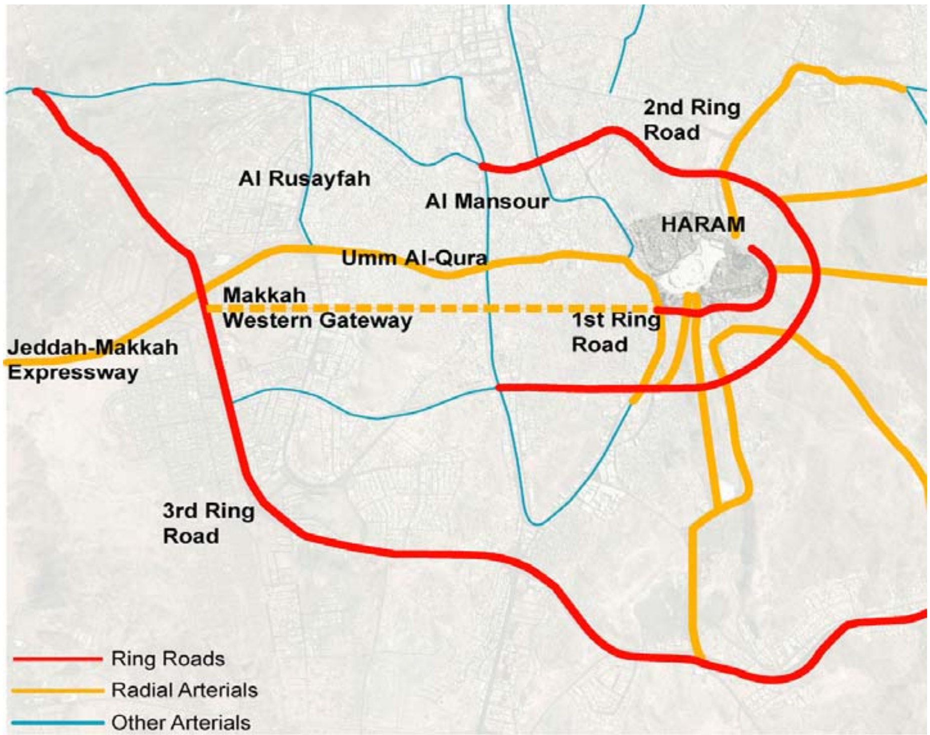

Figure 1: Makkah's Road Network

The Second Ring Road duplicates the function of the First Ring Road at a further distance from the Haram. Like the First Ring Road, the western section of the Second Ring Road is incomplete, but Al-Mansour Street, a North-South arterial street, acts as the de facto western section.

The Third Ring Road is the main road that allows drivers coming from the west to go directly to the south without entering the city.

The area within the Second Ring Road is connected to the rest of the city by radial roads of the network. The radial roads are the main feeders of the Central Area, connecting the ring roads to the center of the city. Buildings along these roads combine residential and commercial use, and are thus important demand generators

This network configuration also allows access to surrounding areas, such as the religious sites of Mina and Arafat (to the southeast), and connections with the main roads and highways leading to other cities, such as Medina and Jeddah. A secondary network that connects the different suburban areas complements this main road network.

2.2 Makkah Western Gateway Project

In order to address the need for improved access to the Central Area from the west, the development of the Makkah Western Gateway (MWG) is proposed. This would serve as a new access corridor connecting the Jeddah expressway with the Makkah Central Area. The MWG, along with the extension of the 1st Ring Road, would serve as an integrated transportation network serving access to the Central Area from the west. The corridor would provide the following transportation components:

- *Roadways* – The MWG would provide roadways to serve different purposes and users. First, express lanes would provide direct, limited-access service from the Jeddah-Makkah Expressway at the western end to the 1st Ring Road at the eastern end. The expressway would be fully integrated with the extension of the 1st Ring Road. Second, local lanes would provide inhabitants with access to the buildings and services along the corridor. Finally, service roads would provide access for commercial and service vehicles, separate from public access points.
- *Mass Transit* – The MWG would provide a mass transportation service for the use of corridor inhabitants and those parking at facilities within the corridor. This system would serve to reduce the number of vehicles attempting to access the Central Area by providing service to a terminal at Jabal Omar, the area directly to the west of the Haram.
- *Pedestrian Facilities* – The corridor would have extensive facilities for pedestrians, again encouraging a non-vehicular mode of transport to the Central Area. These facilities would be used both by corridor inhabitants and by those using parking facilities.
- *Intelligent Transportation Systems (ITS)* – ITS, which is the application of advanced technologies in the field of surface transportation, is proposed to be an integral part of the corridor. Elements such as Traffic Management Systems and Traffic Information Systems would allow the proposed infrastructure to be used at greatest efficiency.

Considering the existing access to the city, the MWG will play a main role in the access system. Umm al-Qura, the main access point from the west, is already running at capacity and is not be able to handle future demands. The MWG corridor will provide another means of access from the west and thus would help in alleviating the traffic problems on Umm al-Qura. It would also be connected to al-Mansour and al-Rusayfah streets and thus would provide an efficient connection to the south and the north.

At the Central Area, the MWG is conceived to connect to the extension of the 1st Ring Road. The two infrastructure projects would complement each other, allowing a direct connection for traffic passing through the city without the need for driving on city streets.

3. Data

The first step in the model development process was the collection and analysis of relevant data. As the available data was known to be quite limited, it was expected that a standard planning model methodology would not be possible to follow. Therefore, the type of data available guided the development of the methodology for the development of the model. Available data was classified into two categories: network data and demand data.

3.1 Network data

Data in this domain consists of the information that allows the definition of all the attributes of the network, such as roadway widths, number of lanes, curves, slopes, grades, and intersections. The primary source of this information was a detailed satellite image of Makkah, a CAD restitution of this image in the study area, and a topographic survey.

Network restrictions implemented during high demand periods (i.e. Ramadan and Hajj) were determined based on the plans produced by the Makkah traffic directorate (Directorate of Hajj Security for Traffic Matters, 2001). Data about a number of signalized intersections, including cycles and phases, was also available from miscellaneous sources. Finally, information on planned developments was gathered, with an eye towards those that would have an influence on the network definition for future scenarios. Information about the characteristics of these new developments and their associated road networks was collected from available documentation.

3.2 Demand data

For defining the demand parameters of the model, the important considerations are existing and future land uses as well as traffic conditions. Data relating to land use was very limited. While general zoning information was available for the study area, specific land uses and densities were mostly not available. Information on major parking areas was the one source of information for major traffic generators. For planned developments, available documentation was used to determine the associated land uses.

The primary source for traffic data was a series of traffic counts undertaken for this study (El Zahrani et al., 2002). These consisted of counts collected in 2002 during Ramadan, Hajj, and off-peak. Counts were taken at locations throughout the city, including an outer cordon (six locations) to capture the major entry and exit points from the city, an inner cordon (10 locations) to capture traffic entering and exiting the Central Area, and intersection counts (14 locations) within the Central Area. For traffic forecasting, the primary source was the Makkah Structural Plan, a 50-year plan the city issued by the municipality (Executive Department of Holy Makkah Plan, 1999).

Key data such as socioeconomic data and origin-destination studies were not available for the area, however, so the model development process had to proceed without this type of data. The following section details the methodology applied.

4. Methodology

Faced with these challenges, alternative approaches were developed and applied in the development of the transport model. This section details the approaches used in the model development, including the network structure and the demand definition.

4.1 Network structure

The network model was developed based on existing data and information assembled for the study. This includes data about the roadway network, traffic and passenger demand on the network, planned projects, and future developments in the region. The geographic files (network files) of the models were developed based on the satellite images and digital restitutions. The following subsections describe the steps involved in developing the geographic files.

4.1.1 Establish boundaries

The immediate area of the Makkah Western Gateway could be considered as the limits of the area that has influence on the study. However, the different trip patterns during the Hajj and Ramadan periods require extending these limits to consider a more representative area. Figure 2 shows the boundaries adopted for the model. External zones were created for each corridor cut by the boundaries. The external zones represent the main flows from the west (Jeddah), south, east (Mina, Arafat), and north (Madinah).

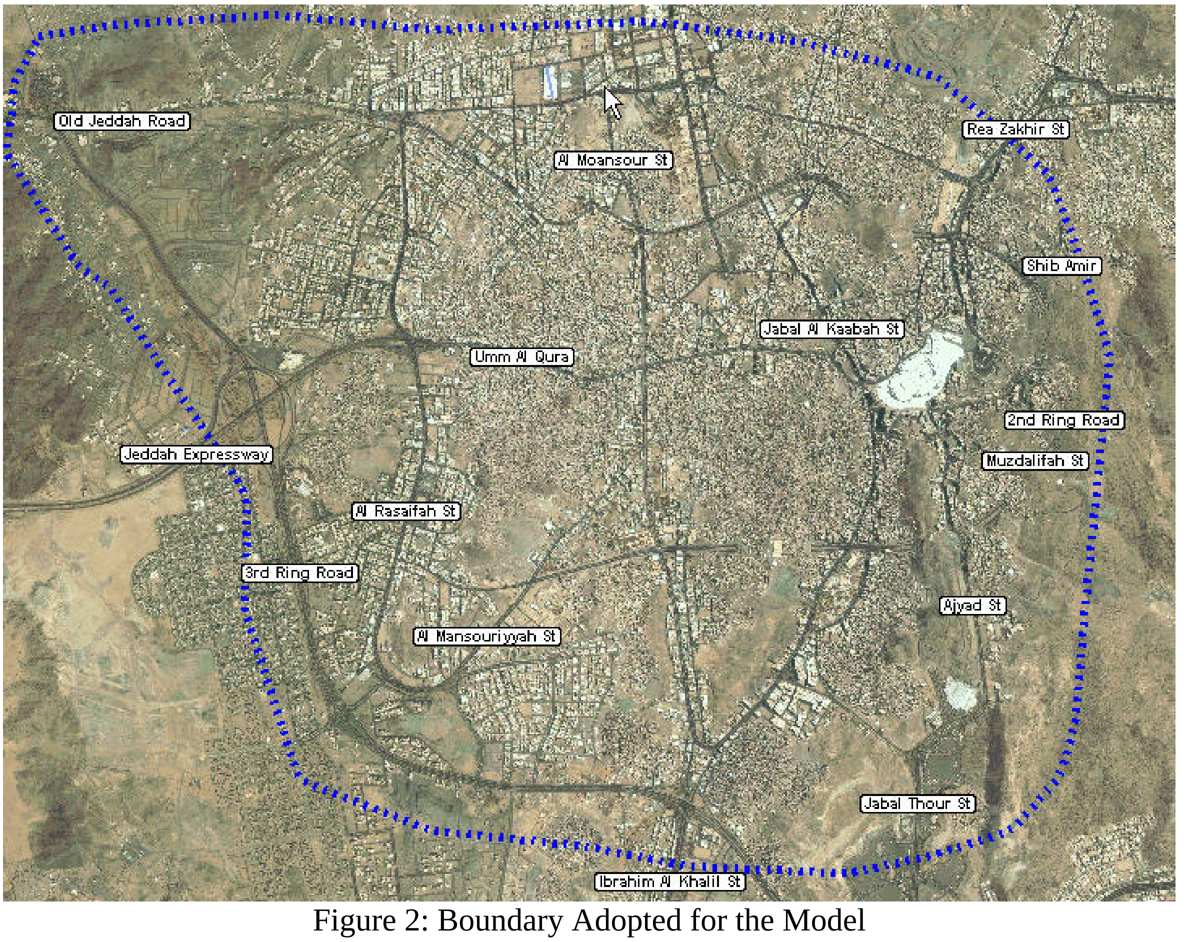

Figure 2: Boundary Adopted for the Model

4.1.2 Establish zones

The next step in developing the geographic files was to define the zones in the network. Typically, the zones are defined based on the characteristics of the area, such as residential areas (single and multi family), commercial areas, and hotels (or short term residences). The information gathered from aerial photographs was used to establish the best zonal configuration, supplemented by characteristics such as land use and the socioeconomic profile of the areas obtained from other sources. A total of 310 internal and external zones resulted from this analysis.

For analysis of the future year conditions, the zones were modified to incorporate the following extra elements:

- New urban profiles and land uses defined by the future developments (including the MWG);
- New road networks associated with planned developments or with planned infrastructure projects;
- New parking facilities associated with planned developments; and
- New road network configuration in the area around the MWG.

4.1.3 Road network

The modeled highway network includes all streets, roads, and highways that make up the regional roadway system. The basic elements of the network are nodes and links. The first step in developing the network was to define the node positions. The node positions were indicated in geographic coordinates to allow flexibility for other future applications.

The next step for developing the network was to define network links. Among the link attributes, the link type, capacity, and free flow speeds had to be established for every link in the network. The road network was classified into six different categories of links: Freeways, Highways, Arterials, Major Urban Streets, Secondary Urban Streets, and Minor Urban Streets.

Geometric definition of the network and its components (roads, intersections, and ramps) were taken from the satellite images and the digital CAD restitution. Capacity of each link was calculated based on the collected information, taking into account the prevailing roadway traffic and control conditions. The capacity of each roadway was calculated based on the HCM 2000. The available data did not contain the estimates of the free flow speeds on the network links. Therefore, the free flow speeds for each road class were assigned based on the HCM guidelines.

4.2 Existing demand

After developing the network, the next step was defining the demand for different scenarios. The challenge of this work was to develop the best OD matrices based on the available data. To obtain an appropriate OD matrix, a good starting seed matrix is required, along with the counts at a reasonable number of locations. In this case there was no seed OD and the counts were limited. Missing data was impossible to obtain within the given timeframe, because the most exigent scenarios represent annual events for which surveys are unavailable.

Figure 3 shows the method that was adopted to estimate the OD matrices for different scenarios. This follows one of the standard OD estimation procedures, with some supplementary modifications and checks to make up for the lack of data. These steps were implemented in TransCAD to obtain the OD matrices. The sub-sections following describe the step-by-step process of OD estimation.

4.2.1 Trip generation

The trip generation process was dictated by the available land use data and movement patterns during religious activities. The following subsections outline the methodology and the applied concepts.

4.2.1.1 Land Use

For modeling purposes, zoning information is essential for defining the densities of various areas and the trip generation and trip distribution relationships. As explained in Section 4.1.2, the zone definition is highly connected with land-use patterns.

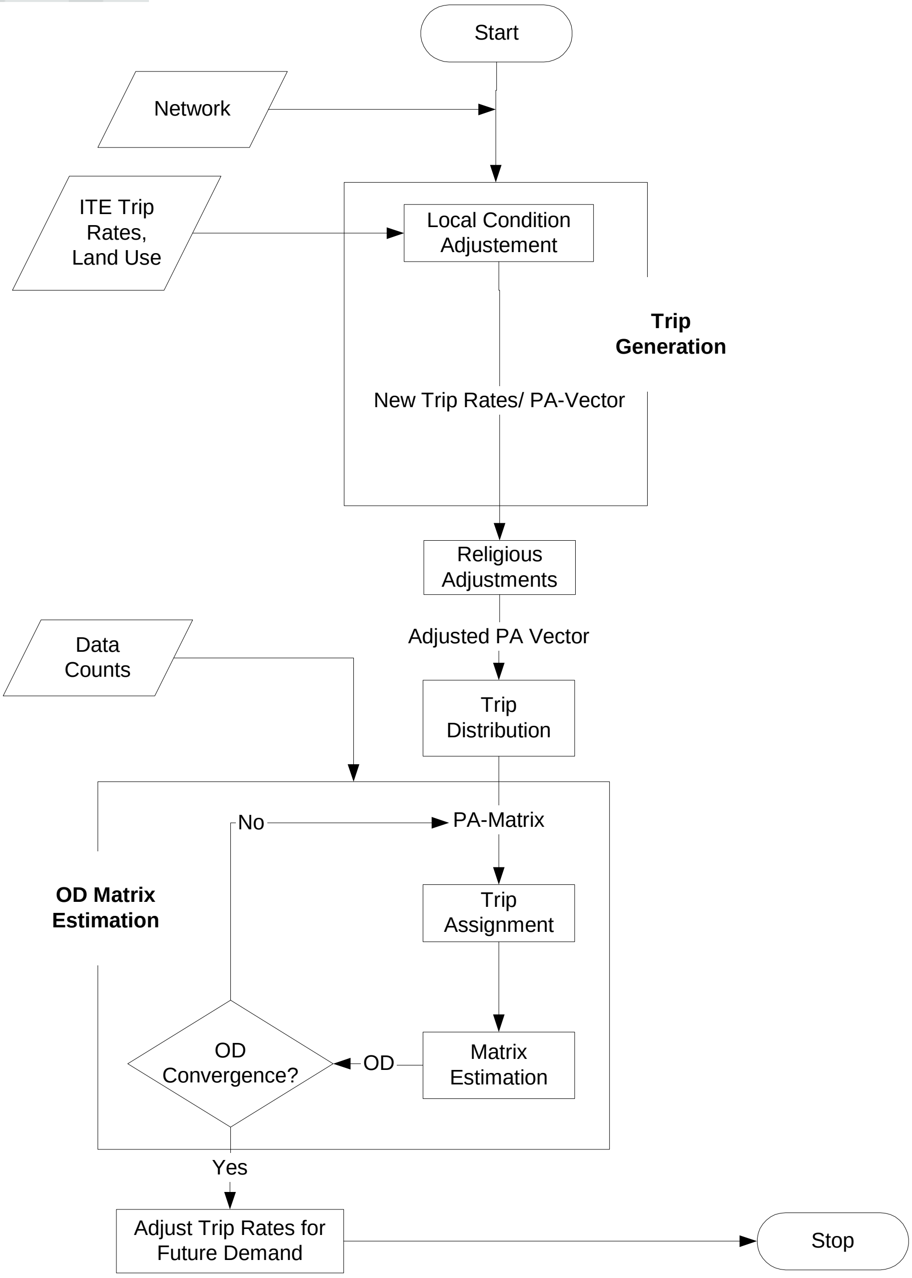

Figure 3: OD Matrix Estimation Process

Land-use data was obtained from documentation for specific development projects. However, the information in these documents is constrained to the implementation areas of these projects, which is smaller than the area adopted for the model.

Hence, the satellite image of Makkah was taken as the main source of information about land uses. It was used to gather information about parameters, such as number of dwelling units in planned urban areas and the floor area of different developments, which were then used as independent variables to establish the trip generation. This information was validated using complementary data sources that included pictures of the area to define the urban profile and building heights as well as available maps describing the distribution of commercial areas and building types.

Information about parking facilities, mainly those areas with a park-and-ride functionality, provided valuable data to define high demand zones. Other main land uses, including high generators of trips such as retail areas, hotels, and industrial areas, were also included in the model to reach a better understanding of the network functionality.

4.2.1.2 Trip Generation Rates

For each land use, depending on the period of the day (generally the PM peak hour of adjacent streets), the trip generation rates were taken from Institute of Transportation Engineers (ITE) rates. Furthermore, these rates were adjusted to local Makkah conditions by using known rates in Makkah and other factors such as level of motorization. The following corrections were applied to the trip rates:

- Correction to match rates used in previous studies: Prior studies contained Makkah-specific trip generation rates for certain land uses, including residential, hotel, and retail (Dar al-Handasah et al., 2000). When specific rates were known, these were used in place of the ITE rates.
- Motorization Factor Correction: This correction was applied to the land uses not scaled above. This factor was applied to adjust for the motorization rate difference between the United States and the Kingdom of Saudi Arabia (KSA). A motorization correction factor of 0.13 was applied to correct the ITE trip rates.

4.2.1.3 Production-Attraction Vector

The productions and attractions for each internal zone were defined based on the land uses of the zone and the adjusted trip rates (

Figure 4). The external zones were assigned Productions and Attractions equal to the actual traffic counts at those locations. Finally, the productions and attractions of each zone were used to obtain the PA vector for the entire region.

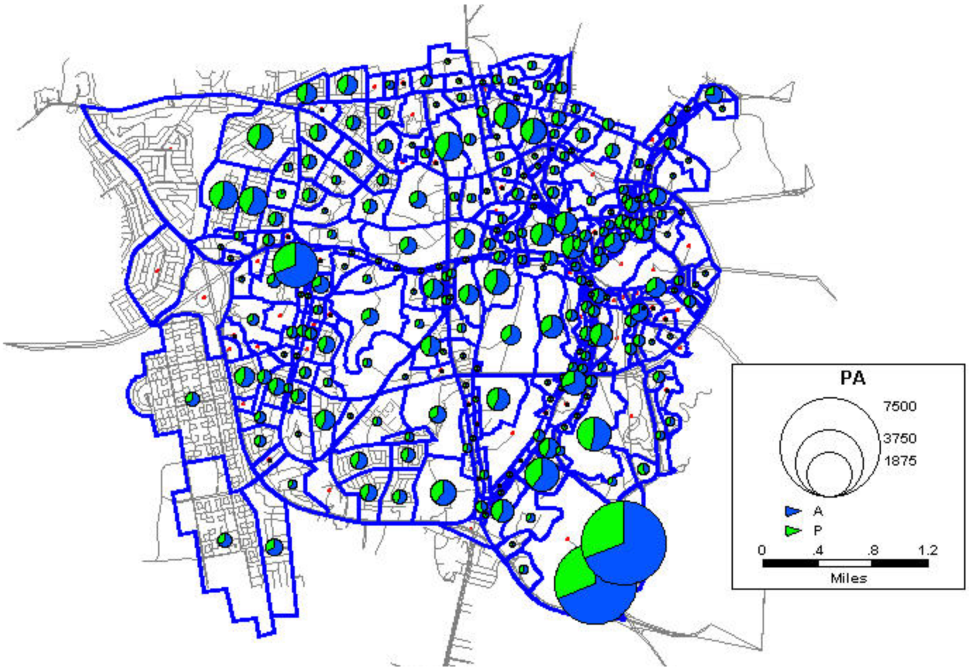

Figure 4: Productions and Attractions – Current Conditions (Internal Zones)

4.2.2 Religious factor adjustment

The estimated PA vector was further adjusted to take into account the movements related to religious periods, which mainly occur within the Central Area. During the peak hour and peak day, most of the attractions and productions are focused near the Haram (the central mosque), and they contribute significantly to the total trips.

As there were no traffic counts taken within the inner cordon, these significant movements in the Central Area are not captured in the traffic counts and are thus not reflected in the estimated OD. Therefore, the productions and attractions in the Central Area were adjusted to account for these trips.

4.2.3 Trip distribution

The next step was to distribute these trips between various zones. The trips were distributed using a gravity model, resulting in a zone-to-zone matrix (PA matrix). Mode split was not considered at this stage, as only vehicular trips were modeled in TransCAD. Because the traffic counts include private vehicles and transit vehicles, however, this mode split is intrinsic to the model.

4.2.4 Origin destination matrix estimation (ODME)

The basic inputs used for determining the new OD are a seed OD matrix, data counts, and the model network. The PA matrix was used as the starting seed OD matrix. The OD was assigned to the network and then, based on the assignment, the new OD was calculated using the OD matrix estimation process.

4.3 Future demand

4.3.1 Demand forecasting

Two factors were considered while projecting the demand for future scenarios:

- Projected growth (based on the Makkah Structural Plan).
- Maximum allowable density in different areas, based on restrictions imposed by Makkah Authorities.

The future demand depends on the growth of the number of pilgrims and inhabitants. Hence, the first step in this task was to define the growth factor that can be applied in different scenarios.

The growth factors are strongly connected to the travel patterns. The travel patterns in Makkah during various periods are quite different. The main reason for this is the difference between the number of residents and non-residents during different periods. Not only does this cause differences in origins and destinations, but also in the facilities used, the number of multimodal transfers, and the trip purpose and frequency. Hence, based on the trip patterns, separate Local and External growth factors were defined.

The relation between the expected areas of urban developments and an increase in the resident and pilgrim population was the key to defining the growth factors. The Makkah Structural Plan (Executive Department of Holy Makkah Plan, 1999) provided information about the expected demographic and infrastructure growth.

Local Growth Factors were defined to estimate the change in the number of future trips due to the local demographic, socioeconomic, and land use changes. Local Growth Factors play a main role in forecasting demand during the Off-peak period and Ramadan period. During both of these periods, the influence of foreigners in daily trips is not very significant.

External Growth Factors were defined to forecast the future trips due to the increase of trips by non-Saudis, particularly during the Hajj, when the participation of foreigners is about 80% near the Central Area. These factors have to be considered in addition to the local growth factors.

The MSP provides information about the areas of future development along with the expected increase of residents and pilgrims. The growth rates from MSP are summarized in Table 1. Since the Ramadan and Hajj periods have different proportions of residents and non-residents, they therefore have different growth factors.

Table **2** shows the growth factor during different periods (Hajj and Ramadan) in future years.

Table 1: Growth Rates

	Year	Inhabitants	Factor
Demographic Expansion	1420 H.	1275000	
	1440 H.	2345000	1.84
	1445 H.	2678750	2.10
	1470 H.	4626000	3.63

	Year	Number	Factor
Number of Pilgrims	1420 H.	2400000	
	1445 H.	4800000	2.00
	1470 H.	4800000	2.00

Table 2: Growth Factors

HAJJ		**1445 H.**	**1470 H.**
70 % Visitors	Growth Factor	2.00	2.00
30% Saudis	Growth Factor	2.10	3.63
	Weighted GF	2.03	2.49

RAMADAN		**1445 H.**	**1470 H.**
30 % Visitors	Growth Factor	2.00	2.00
70% Saudis	Growth Factor	2.10	3.63
	Weighted GF	2.07	3.14

The growth factors calculated in

Table **2** represent the overall population growth in Makkah. The next step was to constrain this growth within the 2nd Ring Road and the 3rd Ring Road based on the maximum density bounds specified by the Makkah authorities:

- Maximum population density allowed inside 2nd Ring Road is 1000 inhabitants/ha.
- Population density between 2nd Ring Road and 3rd Ring Road is capped at 600 inhabitants/ha.

In order to cap the densities within the 2nd Ring Road and 3rd Ring Road, an individual analysis of each zone was done to establish individual growth factor for each zone.

4.3.2 Individual growth factors per zone

The zones were classified into two categories – those with current density above density caps, and those with current density below density caps.

- *Zones with density above the specified density caps* remained unchanged, i.e., population and total number of trips generated in these zones were not changed. The growth of these zones was assigned to other zones, i.e., the growth factors were applied to these zones, and the population in excess of existing population was shifted to surrounding zones or external zones.
- *Zones with population below the specified density caps* will grow according to the proportion of residents and pilgrims in each one (which define the use of external or local growth factors), capped by the maximum values established. In addition, any excess growth from adjacent zones over the cap is also considered.

Within this group, there are also zones without current population. These zones were individually analyzed, and were classified into two subgroups. One group of zones was defined to remain at zero density, as the characteristics of their current land uses or their topography are constraining. The other group was those zones without existing land uses that are close to Central Area or that show signs of future development. These zones were projected to reach the maximum population density in future scenarios.

Land uses for these zones were established as Mid Rise Apartment or Low Rise Apartment. Independent variables for these uses were calculated based on 4 people for dwelling unit. Trip generation rates were calculated based on the independent variables and the trip rates adopted as explained above.

Population changes were projected within each zone, establishing a new "growth factor" based on the original growth factors but limited by the imposed cap for each zone. These factors are equal to 1 if density will not change and above 1 for those that will grow.

According to these projections, densities inside the 3rd and 2nd Ring Roads will be reaching their maximum values by the year 2025. The difference between year 2025 and year 2050 will be the amount of population estimated to live or stay outside the 3rd Ring Road that will be reflected as trip generation from external areas.

4.3.3 Demand forecasting for future developments

In addition, specific planned projects and developments that would be special generators were examined in detail. Many of these developments have density caps greater than those for the surrounding areas, so these zones were considered separately. Trip generation rates were calculated based on the independent variables, the local trip rates, and the religious factor adjustment. These values were modified with an individual adjustment factor due to the population density cap. The trips generated due to the new developments were added to the PA vector calculated above.

4.3.4 Future trips distribution

As described above, growth factors are used for forecasting future demand. However, for the long-term analysis, the growth factors cannot be directly applied to the trip distribution because the new developments and network changes modify the trip distribution. Therefore, the future changes in the network infrastructure were included and the trip distribution was performed again using a Gravity Model, which had been calibrated using the base year data. This trip distribution process resulted in a future OD matrix.

4.3.5 MWG Corridor trips adjustment

The area-wide model uses vehicle trips as the basis for its analysis. As such, the modes considered in the area-wide model are those identified in the count data collected (e.g. cars, buses, trucks, etc.), and the modal split is defined exogenously based on the proportions established by the traffic counts.

The future scenarios that include the MWG corridor, however, need to consider new modes in order to represent accurately the movements within the corridor. These modes include the proposed Bus Rapid Transit (BRT) service and pedestrian trips, which will divert trips from the automobile mode. Therefore, a modal split model for the corridor is required to estimate the mode choice behavior of users of the corridor.

4.3.5.1 Model Estimation Challenges

Mode choice is typically represented with discrete choice models, such as logit or probit models. However, there are two primary challenges in estimating models such as these for the MWG corridor: lack of data, and the unique context of Makkah.

Some data about existing behavior, or revealed preference data, has been collected by means of pedestrian interviews in the vicinity of the Haram (Hariri et al., 1997; Mohamad et al., 1997). However, the surveys did not ask about potential usage of a new mass transit mode. In order to estimate demand for a new mode, such stated preference data is required.

Because this data is not available for Makkah, the alternative is to use data from another comparable city. However, due to unique role of Makkah for Muslims, especially during the Hajj and Ramadan, it is difficult to justify the use of data from another city to estimate a model for Makkah. Due to the holy nature of the pilgrimage trip, not even a basic model based on travel time and cost will be comparable to other locations. For many pilgrims, the trip to Makkah is a once-in-a-lifetime event. Therefore, it could be argued that the effect of cost, such as for parking, would be almost negligible.

The effect of travel time is similarly unusual. For example, because the pilgrimage trip itself has religious value, pilgrims are willing to walk much farther distances than they would in ordinary situations, due to the religious purpose of their journey. Moreover, for most people, a longer trip by foot may be preferred to a shorter trip by another mode. Clearly existing data or models, even from another Saudi city, will not be able to capture the unique nature of Makkah and the behavior of its travelers.

4.3.5.2 Approach

It was clear that estimating a detailed travel demand model for Makkah would not provide credible results. Therefore, instead of estimating a model that will not realistically represent the behavior of travelers, an approach was developed that recognized and addressed the known limitations.

As a demand-side model is not feasible, a supply-side model is recommended instead. Based on the proposed design of the MWG, a number of capacity constraints can be identified that will provide upper bounds on the demand that can be serviced by the different modes. For example, parking lot capacity will provide an upper bound on the number of vehicles that will be destined to the central area, while capacity of the mass transit system will limit the number of transit riders. By developing scenarios that reflect these upper bounds, the model can be used to illustrate the operation of the corridor under the range of conditions that can be expected.

Three scenarios, representing the upper limits on the three primary modes, have been developed. The scenarios are the following:

- *Mass Transit* – Corridor inhabitants will fill the mass transit system to its capacity.
- *Vehicles* – Corridor inhabitants who have vehicles will fill the Jabal Omar parking facility (the closest facility to the Haram) to its capacity.
- *Pedestrian* – Corridor inhabitants will walk to the Haram if it is feasible for them to walk that distance.

The true behavior that is expected will lie somewhere in between these extreme scenarios. These scenarios, therefore, provide the bounds within which the corridor will operate. The execution of the approach consisted of the following steps:

- For each scenario, assign the internal trips (i.e. those generated in the MWG corridor) bound to the Haram to the mode determined by the scenario. If the capacity constraint is exceeded, assign the extra trips to the other modes.
- Take the modal split results from each of the three scenarios, and calculate the centroid. This will produce an intermediate scenario among the three extremes.
- Take the number of internal trips to the Haram by vehicle from the intermediate scenario, and use this number to scale the ODs in the TransCAD model that originate in the catchment area and are destined to the Haram.

5. Scenarios

A series of scenarios was run to evaluate current and future conditions. Scenarios were defined based upon the following parameters:

- Seasons (Ramadan, Hajj, Off-Peak)
- Periods (AM peak, PM peak, Religious Peak)
- Demand (Base Year, 1445 H., 1470 H.)
- Infrastructure (Do-Nothing, MWG, First Ring Road Completion, Full Infrastructure.)

Different scenarios were developed to evaluate the performance of the network. The following scenarios were defined based upon different periods and infrastructure conditions:

5.1 Base year

These scenarios were based upon the current conditions of infrastructure and demand and were developed to define the base network conditions and calibrate the model. Furthermore, these scenarios were adopted as a reference to evaluate future scenarios. Due to the different demand conditions during different periods, three scenarios were developed: Hajj, Ramadan, and Off-Peak.

5.2 Year 1445 H. – Do-nothing scenarios

These scenarios were used to study the network conditions in the future, just considering the forecasted increase of the demand and without adding any new road infrastructure. The initial runs of the base scenario clearly indicated that Ramadan period was the period with the heaviest demand, with many overcrowded areas and bottlenecks in the network. Hence, only the Ramadan period was modeled.

5.3 Year 1445 H. – Partial infrastructure scenarios

To analyze the effect of the future growth under various partial-build scenarios, a set of complementary scenarios was built, all considering the demand of the Ramadan period. The following scenarios were modeled:

- Scenario A: Current infrastructure with planned development projects not associated with infrastructure improvements
- Scenario B: Current infrastructure plus all development projects other than the MWG (including those with infrastructure improvements
- Scenario C: All planned developments and their associated infrastructure improvements (including the MWG and its road infrastructure)

5.4 Year 1445 H. – Full infrastructure scenarios

The full-build scenario considers all the planned developments and their associated infrastructure improvements (as in Scenario C above), but also includes planned roadway infrastructure projects, including the completion of the first ring road. Three 1445 H. full-infrastructure scenarios were developed: Hajj scenario, Ramadan scenario, and Off-Peak scenario.

5.5 Year 1470 H. – Full infrastructure scenarios

The full infrastructure scenarios were also developed for the year 1470 H. for the Hajj, Ramadan, and Off-Peak periods. The year 1470 H. do-nothing scenario was not considered, as the initial runs showed the do-nothing scenario failing by 1445 H.

6. Results

6.1 Traffic

The western area traffic model, which considers vehicle trips alone (adjusted based on the results of the modal split analysis), indicates high levels of congestion during the peak periods of Ramadan and Hajj, with the highest peak occurring during Ramadan. The results presented in this section, therefore, are for the Ramadan peak.

6.1.1 Base year

Figure **5** illustrates the traffic conditions on main roads during the base-year peak hour, which occurs on the 26th day of Ramadan. The width of the roadway represents the flow on that link, while the shading represents the volume-capacity ratio (v/c).

The figure illustrates that the Jeddah Expressway/Umm al-Qura Street corridor and the 3rd Ring Road to the south experience the heaviest demand. The figure also indicates that a number of sections are operating at or above capacity, including some sectors and intersections on Umm al-Qura, and portions of the 3rd Ring Road, Ibrahim al-Khalil Street, and Jeddah Street near Al-Mansour Street.

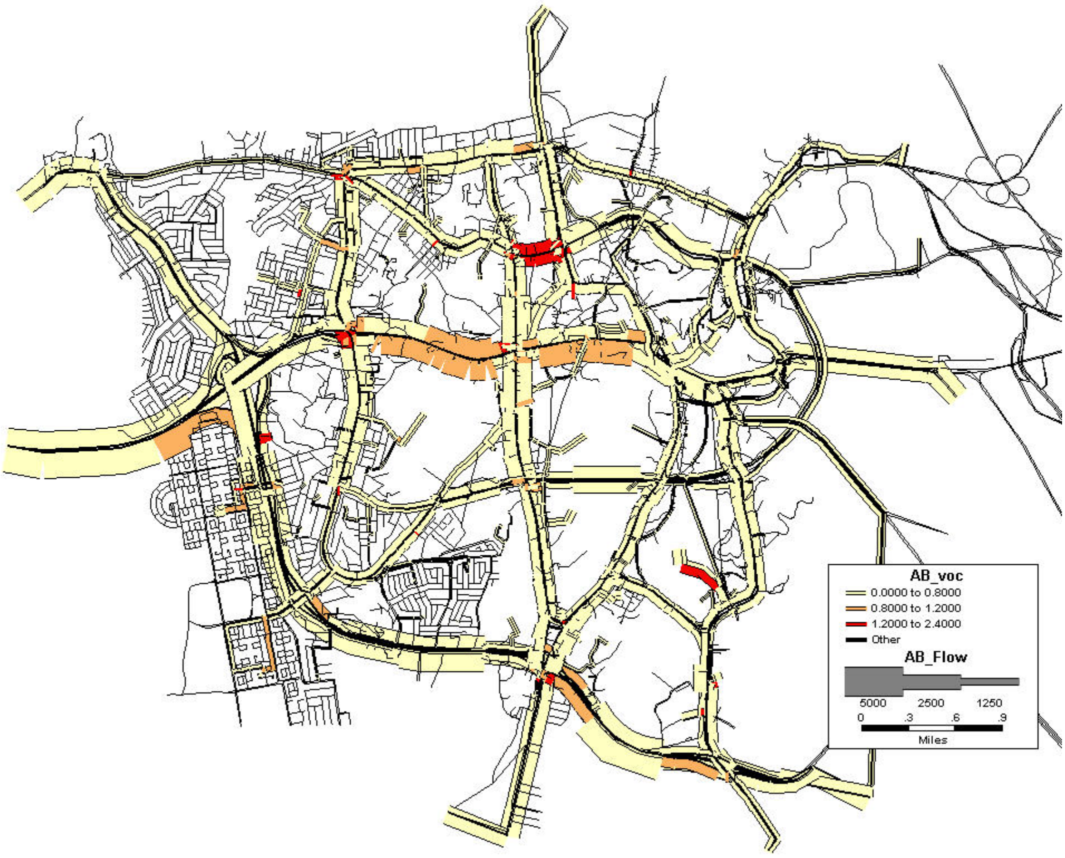

Figure 5: Traffic Conditions – Ramadan Peak, Base Year

6.1.2 Year 1445 H. Do-nothing

Figure **6** presents the future conditions for the Ramadan peak. As expected, the model of the future conditions shows traffic worsening, with heavy traffic volumes in the city. The highest flows are on the Jeddah-Makkah Expressway eastbound and the 3rd Ring Road southbound, both having segments with flows over 10,000 vehicles/hour.

In terms of capacity, western access is of greatest concern, with Umm al-Qura well above capacity for most of its length and with the Jeddah-Makkah Expressway seeing high congestion at its interchange with the 3rd Ring Road. The results clearly indicate that the network needs to be improved and developed to handle the future demand. The network will not be able to handle any further increase in demand without infrastructure improvements.

6.1.3 Year 1445 H. Full infrastructure

The results of this scenario are presented in

Figure 7. The figure shows that the MWG expressway and its surrounding road network experience heavy demand. At the same time, as expected, the flows over the 3rd Ring Road and Umm Al-Qura have decreased as compared to the scenarios without the MWG.

Figure 6: Traffic Conditions – Ramadan Peak, Year 1445 H. (Do Nothing)

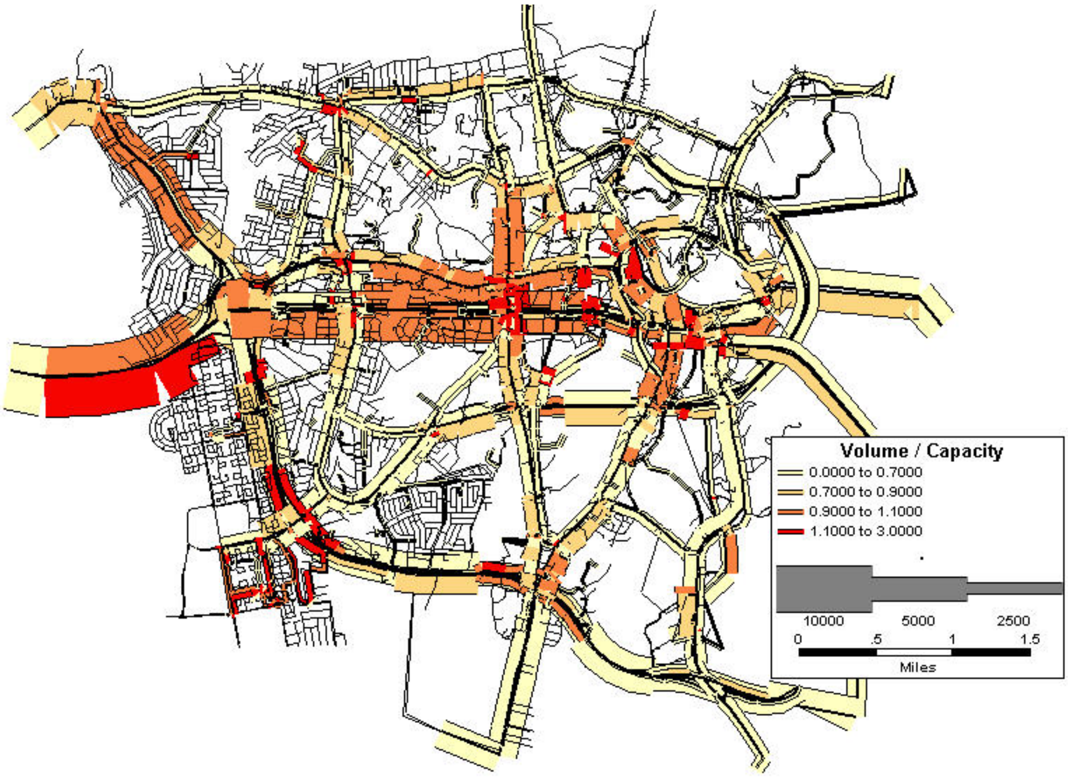

Figure 7: Traffic Conditions – Ramadan Peak, Year 1445 H. (Full Infrastructure**)**

6.2 Transit and pedestrians

The modal split analysis considers peak-hour trips within the proposed western corridor destined to the Haram, the holy mosque in the center of Makkah. The results show that mass transit trips will dominate in the corridor, with the demand for mass transit from the residents of the corridor high enough to approach the anticipated capacity of 10,000 persons per peak hour. In considering the inhabitants of the surrounding area, the results show that the potential ridership of the mass transit system approaches the capacity of the system. This indicates that ridership is likely to be quite large if the corridor is accessible to outside residents, in which case the capacity of the system may ultimately determine the ridership of the system.

Pedestrian usage of the corridor by inhabitants is also shown to be quite high. Furthermore, when pedestrian trips by people choosing to park at corridor parking facilities and then walk to the Haram are considered, this number grows further.

7. Conclusions

This study has demonstrated that planned growth and development will have significant impacts on the operation of Makkah's transportation network. Specific development projects in the Central Area in combination with overall planned growth for the city will lead to major congestion on the roadways of the region if no additional traffic management or infrastructure projects are developed. However, simply adding road capacity will not be an adequate solution, as the capacity of the Central Area is limited, both in terms of parking spaces for vehicles as well as in terms of the capacities of the local streets and ramps to handle additional traffic.

The need therefore exists for integrated multimodal solutions for access to the Central Area, solutions that support access via non-vehicular means, such as transit and pedestrian modes. Access from the west has been shown to be the most critical, as existing roads such as Umm al-Qura and the 3rd Ring Road are either at or approaching capacity during peak periods.

The Makkah Western Gateway, in conjunction with the completion of the 1st Ring Road as part of the Jabal Omar project, has been conceived as a multimodal corridor that will serve movements to and from the Central Area. As shown in the analysis of the 25-year horizon, the MWG will have benefits to the overall road network, not only by creating an additional vehicular route into the center, but also by providing alternatives such as transit and pedestrian facilities for those moving to and from the city center.

However, while the MWG can address much of the anticipated traffic problem in the 25-year horizon, it alone cannot be a solution for the long-term transportation needs of the city. To demonstrate this, the traffic model including the MWG infrastructure was run for the 50-year horizon.

Figure **8** shows the flows and Volume/Capacity ratios for the Ramadan peak.

These results clearly show that there are large flows on the entire network, with the main roads running well over capacity. The East-West corridor, the 3rd Ring Road, and intersections near Central Area are the sites with the heaviest demand. This implies that additional infrastructure will be required, especially to handle demand during the religious periods. This is consistent with the recommendations of the Makkah Structural Plan, which calls for improvements and additions to the radial and ring road network, as well as improved access by transit.

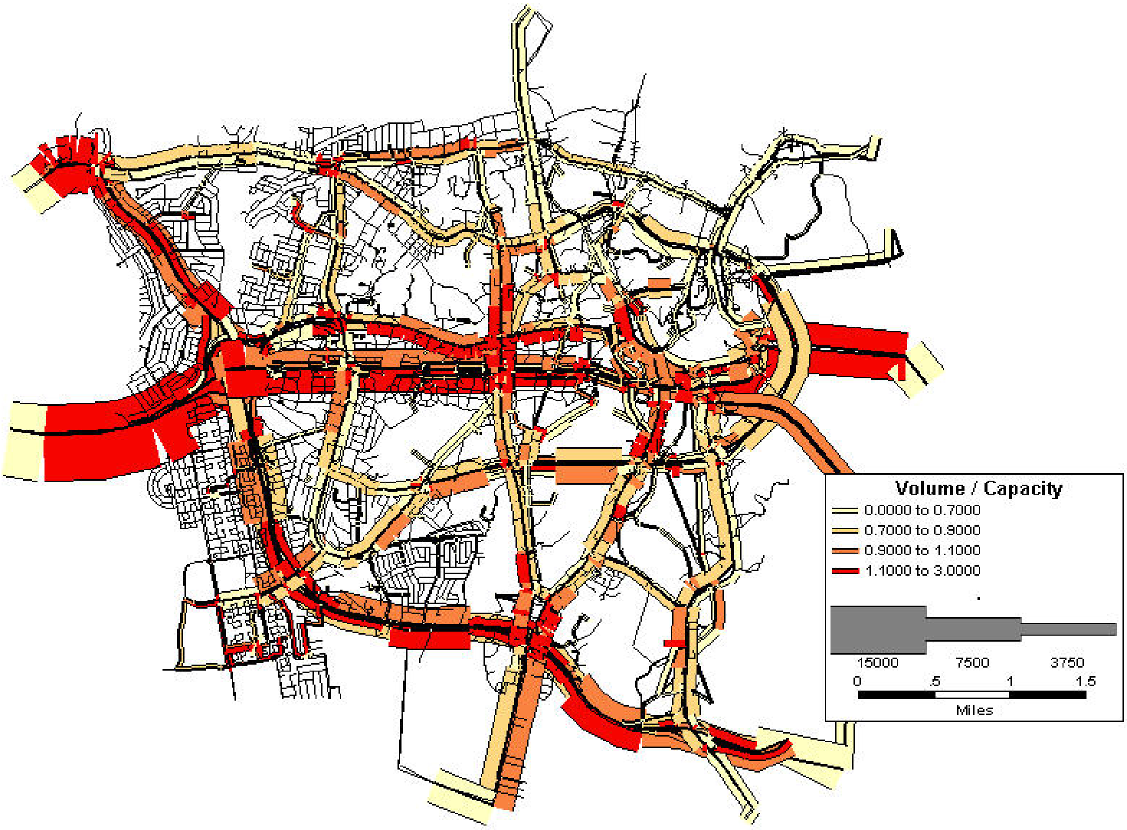

Figure 8: Traffic Conditions – Ramadan peak, Year 1470 H., with MWG

While the MWG has clear benefits in the short- and mid-term horizons, it must be a part of a long-term development strategy in order for the transportation network to remain viable. Therefore, it is vital that the Makkah Structural Plan or other long-term planning vision for the city be adopted and maintained. The MWG, as the first major phase of this plan, will serve as a model and guide for the continued sustainable development of Makkah.

It should be recognized that due to significant limitations in the availability of information, including basic data needed for the development of a transportation planning model, the modeling methodology developed was decidedly non-traditional. However, such an unconventional model development process may be the only option in cases such as this where data availability is severely limited. This consideration must also inform the conclusions that can be drawn from the model, with the limitations of the model taken into account in the analysis of the results.

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