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MODELING AND SIMULATION OF TRAFFIC FLOW: A CASE STUDY - FIRST RING ROAD IN DOWNTOWN MADINAH

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ABSTRACT

Traffic assessment is extremely important for the performance evaluation of vehicle-flow on a road network. This paper presents an assessment of traffic flow on the busiest road i.e., First Ring Road located at the central area of Madinah in Saudi Arabia. In this paper, the assessment of traffic-flow is performed by evaluating and analyzing the traffic on First Ring Road. This includes investigating the number of vehicles entering and exiting the central area through First Ring Road, the arrangements of the road, percentage of traffic entering versus exiting, etc. In addition, a new model for the traffic distribution along the roads intersecting with First Ring Road was built based on optimization. Our optimization model was formulated as a minimization problem of the difference between the measured number of vehicles and the sum of portions of vehicles from all entrances of First Ring Road that move out from each road. A simulation program was developed using Matlab to solve the optimization model. The simulation results show good agreement with the corresponding measurement data of vehicles at First Ring Road. Thus, our model can be used as a prediction model of vehicle movements.

Keywords: traffic congestion; Hajj; traffic network model; optimization

INTRODUCTION

The traffic in the central area of Madinah is the subject of this study. The central area of Madinah shown in Figure 1 encircled by First Ring Road, occupies around 2.16 km^2. The area is accessed by 12 roads which connect First Ring Road. This area is very crowded especially during pilgrimage (Umrah and Hajj) seasons. According to the Saudi Central Department of Statistics and Information, the number of pilgrims during the seasons from 1995 to 2012 increased by approximately 70%. Table 1 shows the number of pilgrims in the last 18 years (Saudi Central Department of Statistics and Information, 2013). Part of the Hajj trip of the pilgrims is to visit Madinah. Therefore, a large number of pilgrims visit Madinah from about a month before Hajj days until about a month after Hajj is over. In addition to this, people coming from abroad for Umrah also visit Madinah during the rest of the year. Thus, more traffic flows on the road network during Umrah and Hajj seasons. It is also noticed that the population of Madinah has increased significantly in the last decade to over one million and it is projected that the population could increase by 50% by 2025 due to economic growth of the city (Saudi Central Department of Statistics and Information, 2013).

Figure 1. Central Area of Madinah (Enclosed by First Ring Road) (Bing Maps, 2013)

Table 1. The Number of Pilgrims for the Years from 1995 to 2012

Year	From Inside Saudi Arabia	From Outside Saudi Arabia	Total
1995	784,769	1,080,465	1,865,234
1996	774,260	1,168,591	1,942,851
1997	699,770	1,132,344	1,832,114
1998	775,268	1,056,730	1,831,998
1999	571,599	1,267,555	1,839,154
2000	549,271	1,363,992	1,913,263
2001	590,576	1,354,184	1,944,760
2002	610,117	1,431,012	2,041,129
2003	592,368	1,419,706	2,012,074
2004	629,710	1,534,769	2,164,479
2005	700,603	1,557,447	2,258,050
2006	724,229	1,654,407	2,378,636
2007	746,511	1,707,814	2,454,325
2008	679,008	1,729,841	2,408,849
2009	699,313	1,613,965	2,313,278
2010	989,798	1,799,601	2,789,399
2011	1,099,522	1,828,195	2,927,717
2012	1,408,641	1,752,932	3,161,573

The traffic in the central area of Madinah has become a major concern for authorities especially during prayer times where heavy crowds dominate between about an hour before and an hour after each prayer realizing that an immediate action has to be taken to ease this problem (Alginahi et al, 2013). Another concern in the city is the air quality and its effects on health. Given the fact that the peak temperatures in the summer exceed 45^{o}C, exhaust gas emission during that period increases causing serious degradation in quality of air. Therefore, the objectives of the work are: to perform the traffic assessment for the central area of Madinah in order to calculate the number of vehicles using First Ring Road at different times of the day; to identify if there are any differences in the level of traffic on certain routes connecting to Ring Road; to calculate the total number of vehicles intersecting with the ring road; and to provide recommendations on the traffic network in the area. The study was carried out between October, 2010 and June 2011 and the supervision of the survey teams was done by the authors of the study.

The literature presents many traffic road network models to address many issues related to traffic research such as noise pollution, air pollution, accidents, traffic prediction, signage, and surveillance. In addition, the concept of green traffic was also addressed in literature (Yu-Fan and Yan, 2011). However, in this work the concentration is on the work related to traffic assessment to model a ring road in the busy area of a city. Traffic assessments are usually carried out by municipalities for new proposed projects or developments, rezoning requests, traffic congestions, future regional planning and conducting traffic surveys in order to study the traffic behavior in accordance to specific future traffic projection. Usually traffic assessment studies the provided recommendation for some improvements to the area. Here, some examples of traffic assessment studies will be presented.

Traffic impact assessment determines the impact of a project or a development on the transportation and traffic systems. The work carried out by Rogidor and Teodoro in Metro Manila in Philippines compared the traffic impact assessment of two cases involving projects in different cities in Philippines the study examined the sustainability of the traffic management and transportation planning strategies. The outcome of the study recommended that the government must take an active role in promoting traffic impact assessment studies to ensure that all involved stakeholders participate in the process in order to carefully assess the impacts to proposed developments (Diliman, 2005).

The purpose of the traffic assessment study performed by Morrison Hershfield Limited for a proposed quarry located in the Dufferin County in Ontario, Canada was to evaluate the impact of traffic from the proposed project site on the level of service, capacity and operations on surrounding roads based on projected future traffic while the project completion is planned for 2021. The analysis was conducted on different scenarios based on the number of trucks entering and leaving the quarry area. The study recommended the following improvements depending on the different analyzed scenarios: adding staggered passing lanes, adding a left turn lane at the intersection and adding a new right turn lane at the intersection (Munir and Pham, 2012).

The study by Baby and Al-Sarawi (2011) aimed at determining the traffic impact for the new township redevelopment project in Kuwait city. This study was carried out at different times of the day for thirteen different roadway locations in order to study the impact of the project on the roadways. The study concluded that by 2013, the performance of the roadway network would deteriorate due to the projected growth in traffic. By the year 2016, the construction of the project will come to completion and the projected growth of traffic volumes is 30% over the present traffic (2007). Therefore, the impact of the future traffic on the roadway network will be significant, the amount of fuel consumption by vehicles will also increase significantly producing higher Carbon Monoxide (CO), Nitrogen Oxide (NO2) and Volatile Organic Compounds (VOC) emissions which will have a significant impact on air pollution and effect of air pollution on public health. URS Canada Inc. conducted a transportation assessment of potential traffic effects in the Durham and York regions in Ontario because of a proposed thermal treatment facility which would be developed in the municipality of Clarington. The assessment reported that the project was anticipated to account for 2% – 3% of the total trips generated. It also concluded that traffic signals could be required, widening of some roads could also improve the traffic operations, and improvements to the ramp terminal intersections by the ultimate 2023 horizon year with the construction of Clarington Energy Business Park (CEBP).

The impact of traffic on air pollution has generated limited studies. Therefore, the review of traffic related air pollution exposure assessment studies is important. Han and Naeher (2006) provided a review of traffic related air pollution exposure assessment studies in the developing world. They also discussed the available standards for the pollutants: Particulate Matter (PM), CO, NO2, VOC and Polycyclic aromatic hydrocarbons (PAHs). The review also presented the advantages and disadvantages of various monitoring methods for these pollutants in exposure assessment studies. The paper concluded by presenting the limitations and gaps in the available studies and provided some recommendations for future research on traffic air pollutants in the developing world.

Some other work related to traffic modeling include the work of Li and Lu who presented a model for a new short-term freeway traffic flow predication based on combined Neural Network (NN) approach consisting of self-organizing feature map (SOM) and Elman NN, where the SOM was used to classify the traffic condition and the Elman NN identified the relationships between input and output in order to produce the prediction value. As a case study, performance of this model was estimated using real observation data from a freeway in Beijing, China (Li and Lu, 2009). The work in (Xu, Kong, Lin, and Liu, 2012) proposed a spatial prediction approach based on a macroscopic urban traffic network model. This work concentrated on mechanism of vehicles transmission on road segments and the spatial model of the network in addition a speed density model was used to acquire the vehicle travel time in the network. Then, traffic simulation software, CORSIM was used to simulate the real urban traffic. The simulation results of the software produced the effective prediction timings in particular during rush hours and sudden change in traffic states. The work of Jin presented a link queue model of network traffic flow where the changes in the link density describe the different congestion levels on a road link. This model could capture some features of the link traffic flow such as capacity, jam density free-flow speed. When incorporating a junction flux functions it could also describe the propagation, initiation and dissipation of traffic queues within a road network which might be caused by different types of bottlenecks (Jin, 2013).

This paper presents a detailed assessment study of traffic flow within the central area of Madinah along First Ring Road during Hajj and Umrrah seasons to reflect the maximum vehicle flow in this area. The study entailed a comparison among the roads leading to this area in terms of traffic flow nature, peak times, bottlenecks, and traffic distribution. In addition, a new optimization model for the traffic distribution along the roads intersecting with First Ring Road was formulated in order to determine the traffic characteristics on the road network.

The rest of the paper is organized as follows: section 2 describes the methodology and materials, section 3 provides the Results and data verification, section 4 discusses the proposed road network model for First Ring Road and the simulation results, and finally section 5 concludes the paper.

METHODOLOGY AND MATERIALS

Data collection was carried out in the area of study which is First Ring Road surrounding the central area of Madinah. From surveying the area, it is concluded that First Ring Road is accessed by 12 roads which connect to it. Figure 2 shows the location of these roads and Table 2 provides some detailed description for each road.

Figure 2. Location of roads (Google Maps, 2013).

Table 2. Description of All Roads Connecting to First Ring Road

1.	**King Abdul-Aziz Road**: This road extends to 3 km until Second Ring Road at the east side of Al-Masjid Al-Nabawi. This is a two-way road, leading to and away from Al-Masjid Al-Nabawi, with three lanes each. It is used as the main entrance for the people travelling from eastern cities e.g., Riyadh and Qassim. Locally the area around this road is mainly residential. This road will have a bigger importance in the future when it becomes the main link between the Knowledge City and Madinah center area.
2.	**Ali Ibn AbiTaleb Road**: A narrow road with two lanes extends to 5 km to connect the two ring roads through a heavy residential area in the southern east side of Al-Masjid Al-Nabawi.
3.	**Qurban Road**: This road makes the main connection between the two main mosques of Madinah; Al-Masjid Al-Nabawi and Qubaa. It extends south to 5 km with two lanes through a heavy residential and shopping area.
4.	**Qubaa Road**: This road extends for 1.6 km with two lanes through a heavy residential and shopping area at the south-west direction of Al-Masjid Al-Nabawi.

Table 2 (Continue)

5.	**Omar Ibn Al-Khattab Road**: This a vital busy road that extends for about 1.6 km at the western side of the central area connecting Al-Masjid Al-Nabawi with Second Ring Road. This road is considered the main Madinah entrance for travelers to and from Makkah. It is also used heavily by locals due to the fact that the Emarrah (City Hall) is located at its end at the point it merges with First Ring Road.
6.	**Al-Salam Road**: This road connects the central area with Second Ring Road until the two main universities of Madinah, Taibah University and Islamic University of Madinah. Designed as a highway with three lanes on each side for about 1.9 km until Second Ring Road.
7.	**Alemam Alshafai Street**: A one lane road which ends in First Ring Road from AlSeeh area. It is the road parallel to Al-Salam road in the north side. The traffic flow of this road is noticed to be continuous at different peak times of the day.
8.	**Harb Street**: is a two-way street located to the north side of Aleman Alshafai Street in the Seeh area and connects to First Ring Road. However, this road was not considered in this study since the traffic flow into the Ring Road is very minimal and is not that significant.
9.	**Abu-Bakr Al-Siddiqi Road (currently known as Sultana Road)**: This road extends from the central area of Madinah to the main shopping areas at the northwest side Al-Masjid Al-Nabawi for about 2.25 km. Represented in two directions, leading to and from the central area, with three lanes each. It is also a main connection to other major roads going to and leaving the central area which are not connected to First Ring Road (Othman Ibn Affan Road, Sayeed Alshuhada’a Road, ...).
10.	**King Fahd Road**: With two directions of three lanes each, this road extends north out of the central area for about 2.5 km connecting the area with Second Ring Road. Mainly used by travelers to Makkah.
11.	**Abu-Dhar Algefari Road**: Abu-Dhar Algefari Road extends between First and Second Ring Roads and passes through the taxi station and bus station (SAPTCO) area. During the peak seasons of Hajj and Umrah, the section between Airport Road and First Ring Road is blocked for traffic flowing into the central area in order to reduce the traffic flow in First Ring Road. Therefore, this road was not considered in this study since the flow of vehicles into First Ring Road is not significant and is diverted to King Fahd Road and Airport Road.
12.	**Alabbas Ibn Abdul Mutalib Street**: This road connects the central area with the Airport Road at the northeast side of Al-Masjid Al-Nabawi. It extends for 3.3 km between the central area and Second Ring Road. Designed to take from and to the airport with three lanes on each side, it passes through crowded residential and shopping areas.

Vehicle count data collection is divided into 3 parts as follows:

1. MetroCount traffic survey systems (automatic vehicle counts) placed on main roads connecting to the central area of Madinah were used to automatically count the number of vehicles going in and out of First Ring Road of Madinah surrounding Al-Masjid Al-Nabawi.
2. Manual vehicle counts were carried out by subjects (students) using hand-held counters, on the secondary roads connecting to the central area.
3. Manual Vehicle counts at major 3-way and 4-way intersections conducted by subjects to count the number of vehicles in different directions of the 3-way and 4-way intersections. These intersections are junctions of King AbdulAziz Road, Omar Ibn AlKhattab Road, Quba’a Road, Qurban Road and Abu-Bakr Al-Siddiqi Road with First Ring Road.

For the automatic vehicle counts, data collection was limited to five roads only due to the scarcity of metroCounters and the limited project budget. After surveying the area under study, the five busiest roads were identified then the metroCounters were placed on the following roads: King AbdulAziz Road, Ali Ibn AbiTableb, Omar Ibn Al-Khattab, Abu-Bakr Al-Siddiqi Road and King Fahd Road. The manual count was used with the rest of the roads.

RESULTS

Automatic Ingoing Vehicle Counts

From the data collected using the metroCounters on the major roads all roads surveyed throughout the day appear to have the same trend (behavior) as shown in Figure 3. Therefore, the average of the data collected from all days for all roads is calculated. Figure 3 combines the hourly average number of vehicles travelling over different days in 24 hours on all roads measured using metroCounters. The graphs show a similar trend in traffic flow on all the roads connecting to First Ring Road; however, with different traffic flow rates since this depends on the number of vehicles traveling from the different parts of the city into the central area.

Automatic Out-Going Vehicle Counts

The roads surveyed for the ingoing vehicle flow into the central area of Madinah were also surveyed for the out-going vehicle flow except for Ali Ibn AbiTaleb Road which is a one-way street flowing into First Ring Road. The average vehicle flow traveling out of the central area of town during 24 hours of the day from the four roads measured using metroCounters is shown in Figure 4. It is very clear from the graphs that the trend for the outgoing traffic flow is similar for all the roads surveyed and this observation can be applied to all outgoing traffic for all other roads not surveyed.

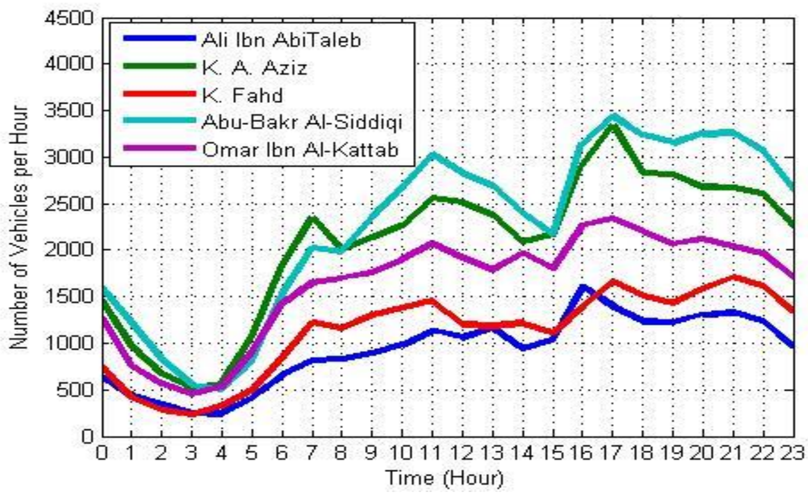

Figure 3. Average number of vehicles travelling over different days in 24 hrs. on all Roads

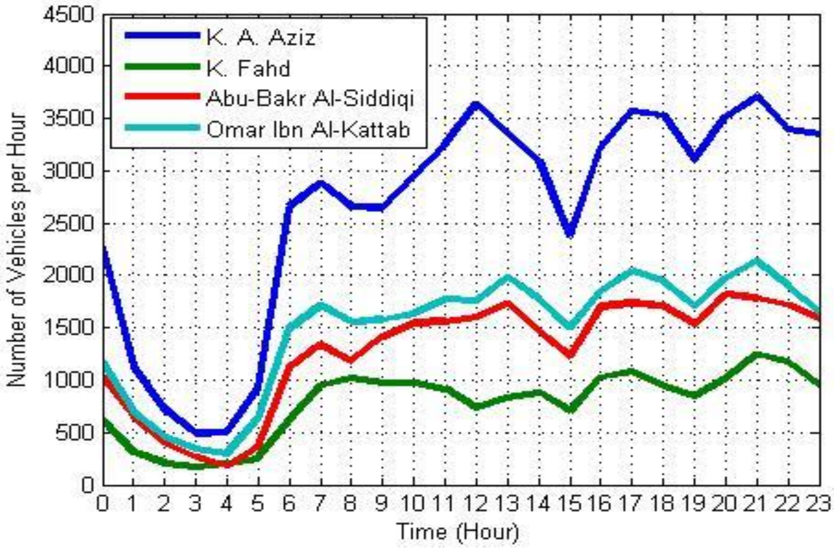

Figure 4. Average number of vehicles travelling over different days in 24 hrs on all roads.

Manual Vehicle Counts

With the aid of a group of students from the college of computer science and engineering at Taibah University the number of vehicles from the secondary roads (not surveyed using metroCounters) flowing into First Ring Road were counted using manual hand counters. The data was collected at different times and days during the Hajj season before and after the Hajj days. It was very difficult managing the data collection process at the same time for all the roads. Therefore, the average number of vehicles was calculated for all the secondary streets flowing into First Ring Road between 8:00 A.M. and 9:00 P.M. The manual count did not consider the times between 9:00 P.M. until 8:00A.M. and this could be a limitation in this study due to the fact that only 5 metroCounters were approved for this study and it was difficult to have the students available all the time during the day and night hours. This part of data collection was combined with the metroCounters in order to determine the total number of vehicles using First Ring Road between 8:00 A.M. and 9:00 P.M. Table 3 shows the data collected from all roads surveyed between 8:00 A.M. and 9:00 P.M.

From the data provided in Table 3, Figure 5 presents the graphs for the average vehicle count for all roads separately. From this figure, the traffic flow is not uniform for all the roads and different behavior is noticed. Most roads show the same behavior of the average vehicle count of all streets shown in Figure 5, with the exception of Quba'a Street and K. Fahd exit ramp that flows into First Ring Road. Most of the roads show the PM peak between 4:00 and 5:00 P.M. which is confirmed from the average vehicle count for all roads shown in Figure 6. On the other hand, the AM peak time is around 12:00 noon. The peak average vehicle count is approximately 2000 vehicles and the average hourly vehicle flow is 17,495 vehicles/hour. The traffic flow is shown to increase from the middle of the morning rush hour at 8:00 A.M. until around noon time then it slightly decreases. It starts to pick up around 3:00 P.M. after that it peaks around 5:00 P.M. after which the traffic decreases until probably the early morning hours where it starts increasing again.

Table 3. Average hourly data for all roads connecting to First Ring Road between 8:00 A.M. to 9:00 P.M.

	Alemam Alshafai St	Al-Salam	Quba'a	Qurban	Ali Ibn AbiTaleb	King Abdul-Aziz	Alabbas Ibn Abdul Mutalib	K. Fahd	K. Fahd exit - ramp	Abu Bakr Al-Siddiqi	Omar Ibn Al-Khattab	Total
08:00	1875	1389	914	1762	819	2008	832	1149	155	1989	1736	14625
09:00	1723	1512	908	1469	879	2058	637	1269	228	2239	1758	14678
10:00	2011	1642	896	1223	953	2211	817	1347	319	2606	1856	15880
11:00	1822	1369	878	1349	1069	2450	710	1449	444	2952	2040	16532
12:00	2144	1951	886	1241	1121	2643	807	1274	320	2947	2035	17369
13:00	2414	1702	897	1165	1146	2408	786	1152	305	2718	1851	16545
14:00	2273	1789	853	1085	993	2179	742	1230	262	2468	1962	15834
15:00	2185	2008	837	1952	970	2142	657	1140	269	2193	1800	16152
16:00	2693	2022	1246	1788	1504	2657	852	1283	292	2841	2166	19344
17:00	2477	2151	1840	1594	1547	3315	948	1646	358	3522	2378	21776
18:00	2471	2219	1806	1306	1150	2853	808	1487	342	3126	2219	19789
19:00	2170	2063	1783	1594	1271	2995	751	1522	381	3323	2138	19990
20:00	2357	2096	1630	1306	1263	2619	684	1474	274	3113	2101	18915
Total average number of vehicles into First Ring Road from all roads between 8:00 A.M. and 9:00 P.M.												227428

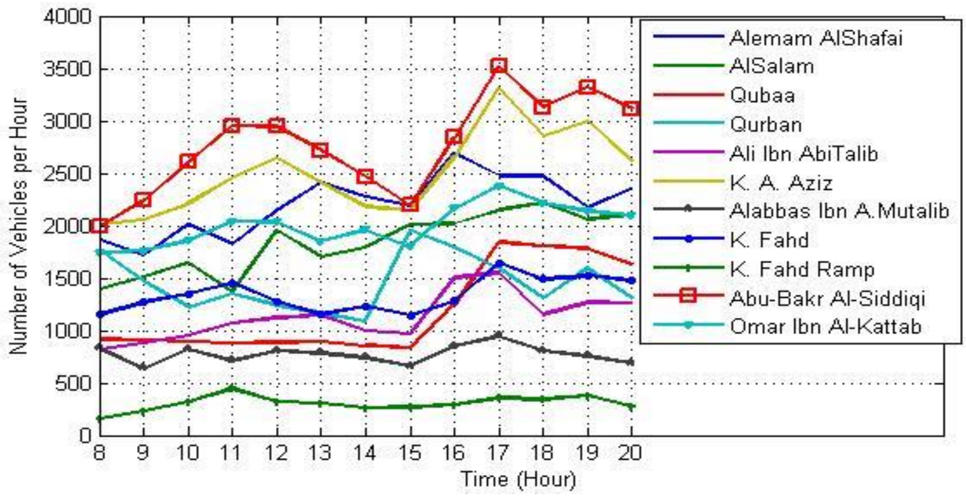

Figure 5. Hourly traffic behavior for all roads between 8:00 A.M. and 9:00 P.M.

The total amount of traffic flowing into First Ring Road between 8:00 A.M. – 9:00 P.M. is 227,429 vehicles. This shows that the total number of vehicles flowing into First Ring Road could exceed the 350,000 vehicles/day in a 24-hour period. Table 4 shows the average vehicle count in an interval of 15 minutes between 7:30 – 7:45 P.M. The two main roads which contribute to a total highest percentage flow of 32% are King AbdulAziz Road and Abu-Bakr Al-Siddiqi Road with approximately 16% each. The other three roads contributing approximately 33% of the traffic flow, each approximately 11%, are Alemam Alshafai Street, Omar Ibn Al-Khattab Road and Al-Salam Road. Therefore, four of these roads confirm to the choice of the busiest roads chosen for the automatic traffic count and the only road which did not confirm with the findings is Ali Ibn Abi-Taleb Road. The central Madinah enclosed by First Ring Road was divided into 5 different areas as shown in Figure 7.

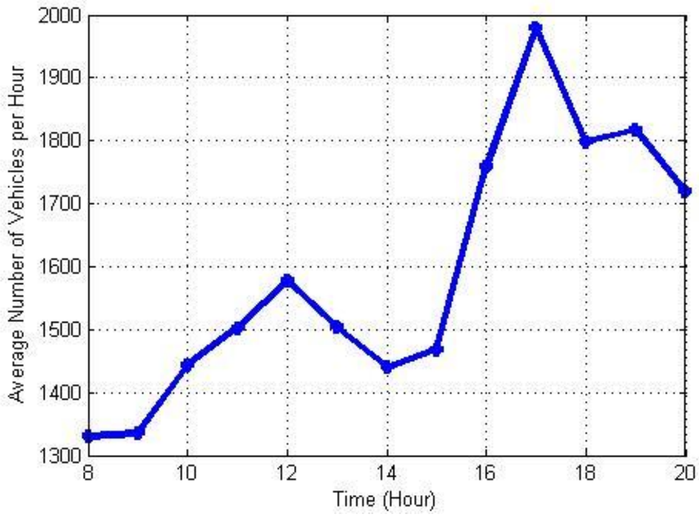

Figure 6. Average hourly traffic behavior for all roads between 8:00 A.M. and 9:00 P.M.

Table 4. Percentage traffic flow during the peak average time using 15 minutes interval.

Name of the Road	Peak	%
King Abdul Aziz Road	928	16.4
Ali Taleb	387	6.8
Qurban	344	6.1
Quba	450	8
Omar Ibn Al-Khattab	624	11
Al-Salam	579	10.2
Alemam Alshafai St	648	11.5
Abu-Bakr Al-Siddiqi Road	909	16.1
King Fahd ramp	92	1.6
King Fahd	456	8.1
Alabbas Ibn Abdul Mutalib Street	236	4.2
Total	5653	100%

The traffic flow between King AbdulAziz Road and Abu Bakr Al-Siddiq Road shows the busiest section of First Ring Road, contributing approximately 46.4% of the traffic flow in the area as presented in Table 5. This section of First Ring Road contributes about 1/3 of Ring Road and therefore, the reasons for the highest traffic flow in this section of First Ring Road are: it contains two major roads connecting to First Ring Road, heavily populated area with many hotels; it has close proximity to Second Ring Road which can be accessed from many other streets in the area; it contains some old residential parts of Madinah; finally it is the location of many businesses and service areas such as a hospital, bus terminal etc. The outgoing and ingoing traffic were compared by considering the total average traffic flow for all days surveyed from the four main roads using the metroCounters data collected during the 24-hour period. Table 6 shows the comparison for the only four roads surveyed for both ingoing and outgoing traffic.

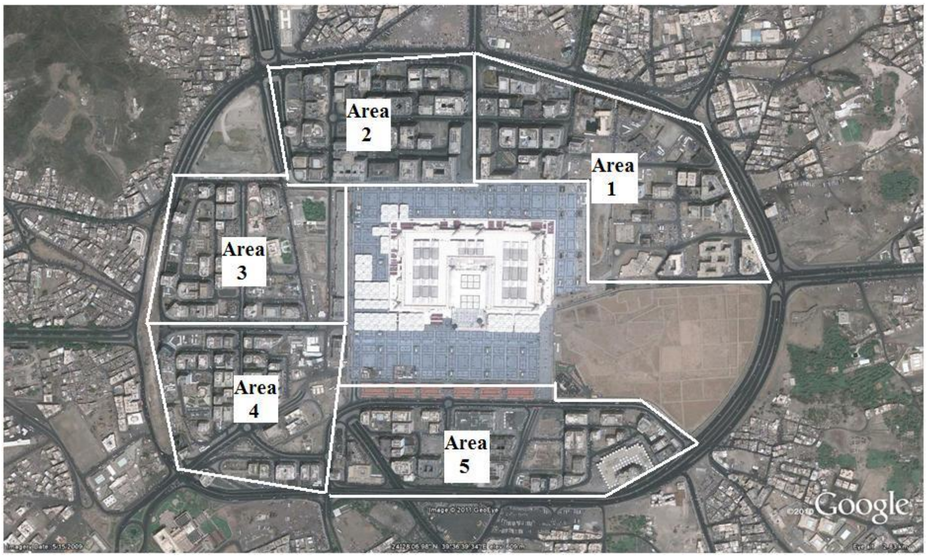

Figure 7. The central area of Madinah divided into five different sections (Google Maps, 2013)

Table 5. Percentage traffic flow according to different areas on First Ring Road

Area	Location	Percentage of Traffic Flow
1	King Abdul-Aziz Road + Alabbas Ibn Abdul Mutalib Street + King Fahd Road	28.7%
2	King Fahd (ramp) + Abu Bakr Al-Siddiq	17.7%
3	Alemam Alshafai St + Al-Salam Road	21.7%
4	Omar Ibn Al-khattab Road	11.0%
5	Quba'a + Qurban + Ali Ibn Abi-Taleb	20.9%

Table 6. Ingoing and outgoing traffic comparison

	King AbdulAziz	King Fahd Road	Abu-Bakr Al-Siddiqi Road	Omar Ibn Al-Khattab	Total
Total average outgoing traffic flow (Out)	55532	18642	30697	35605	140476
Total average ingoing traffic flow (In)	49763	20833	54403	39337	164336
Ratio (Out/In)	111.593	89.483	56.4252	90.5127	85.481
(Out/Total In) * 100 / Total Ratio(Out/In)	0.395313	0.132706	0.218521	0.25346	100

From Table 6 it is very clear that King Abdul Aziz Road followed by Omar Ibn Al-Khattab Road takes the most of the traffic out of the central area of Madinah. Their proximity to Second Ring Road which provides an easy exit from the area can be a main reason for that. Another reason might be the fact that the traffic from Al-Masjid Al-Nabawi’s underground parking lot is directed through them. Also, it is noticed that traffic is flowing smoothly on these two roads due to minimum number of traffic lights installed. However, Abu-Bakr Al-Siddiqi Road has a moderate outgoing flow of traffic since it passes through a heavy business and residential area. Thus, the people avoid using it to go to Second Ring Road. On the other hand, King Fahd Road has the lowest outgoing traffic since it does not directly meet Second Ring Road as well as it does not have a direct connection with Al-Masjid Al-Nabawi parking lot.

Traffic Diversion on First Ring Road

The main roads in Madinah end at First Ring Road. From the main road, vehicles can turn right, left to First Ring Road or straight into the central area. A pilot study was performed to determine how much percentage of the total traffic is diverted to either of these directions. It has also been noticed that the majority of traffic represents a counterclockwise traffic nature for the whole area as shown in Table 7.

Table 7. Percentage traffic diversion from First Ring Road

Road Name	Left	Right	straight
King Abdul-Aziz	65	21	14
Ali Ibn Abi-Taleb	0	100	0
Qurban	0	30	70
Quba	0	40	60
Omar Ibn Al-Khattab	41	49	10
Al-Salam	0	100	0
Alemam Alshafai Street	0	100	0
Abu-Bakr Al-Siddiqi Road	0	55	45
King Fahd ramp	0	100	0
King Fahd Road	0	100	0
Alabbas Ibn Abdul Mutalib Street	0	100	0

Table 7 shows that with the exception of some roads leading to the left direction. King AbdulAziz directs 65% of the traffic to the left, 21% to the right and, 14% straight. From Omar Ibn Al-khattab road, 49% of vehicles turn right, 41% left, and 10% move straight into Al-Masjid Al-Nabawi area. Quba'a road directs 60% of its traffic towards Al-Masjid Al-Nabawi area and 40% to the right on First Ring Road. 30% of Qurban road traffic is directed to the right while the rest flows straight towards the tunnel. 55% of traffic of Abu-Bakr Al-Siddiqi Road flows to the right on First Ring Road and 45% is discharged through the tunnel. Alabbas Ibn Abdul Mutalib Street, Abu Dhar Algefari and King Fahd roads are all located close to each other (within about 600 m). Beside pedestrians-crossing portions of First Ring Road become the busiest area causing high traffic congestion. Same phenomenon is noticed at Alemam Alshafai Street, Al-Salam Road and Omar Ibn Al khattab Road which are located within a distance of 430 m.

Data Verification

In this section, we performed data verification by statistical analysis. Table 7 presents the sample data of all averages of traffic flow from 8:00 AM to 9:00 PM for all streets. A two-way analysis (row- and column-wise) of variance is conducted using the statistical software Anova to test the interaction between streets at different times of the day provided in Table 8. Anova calculates the total sum of squares values (SS), degree of freedom (DF), mean square (MS), F statistics (F-value), probability (P-value) and critical F value (F crit). Detail explanation of these terms can be found in any standard book of statistics. The P-value of the test represents a significance difference between streets and between times of the day. Based on the computed F-value we conclude that at least one non-zero interaction effect exists for at least one treatment (cell). Since the computed value exceeds the critical, the null hypothesis of no main effects from time of the day of traffic flow must be rejected at P=0.05. Also, the computed value of F=162.46 leads to rejection of null hypothesis of identical mean traffic volume for all streets.

A correlation test resulted in a high positive correlation between streets especially those with high traffic volume representing a linear relationship between the streets traffic volume and the time of the day. Although the results do not reveal the main reason for this high correlation between streets, it can be related to either the traffic volume of these streets, to the proximity nature of the streets, or to both reasons as in the case of Abu Bakr and K. AbdulAziz, and K. AbdulAziz and Omar Ibn Alkattab, given in Table 9.

Table 8. Two-way ANOVA results

Source of Variation	SS	DF	MS	F-value	P-value	F crit
Rows	5490993	12	457582.8	10.17288	1.51E-13	1.833695276
Columns	73079928	10	7307993	162.4696	8.49E-65	1.910461065
Error	5397680	120	44980.67			
Total	83968602	142				

Table 9. Correlation results

	Alemam Alshafai St	Al-Salam	Quba'a	Qurban	Ali Ibn AbiTaleb	King Abdul-Aziz	Alabbas Ibn Abdul Mutalib	King Fahd	King Fahd exit ramp	Abu Bakr Al-Siddiqi	Omar Ibn Al-Khattab
Alemam Alshafai St	1.00										
Al-Salam	0.79	1.00									
Quba'a	0.53	0.73	1.00								
Qurban	0.03	0.12	0.11	1.00							
Ali Ibn AbiTaleb	0.78	0.69	0.69	0.13	1.00						
King Abdul-Aziz	0.59	0.72	0.85	0.01	0.87	1.00					
Alabbas Ibn Abdul Mutalib	0.49	0.25	0.35	0.04	0.53	0.54	1.00				
King Fahd	0.22	0.46	0.83	-0.11	0.62	0.83	0.31	1.00			
King Fahd exit - ramp	0.15	0.24	0.35	-0.25	0.47	0.63	0.13	0.66	1.00		
Abu Bakr Al- Siddiqi	0.51	0.63	0.79	-0.22	0.81	0.95	0.41	0.87	0.76	1.00	
Omar Ibn Al-Khattab	0.65	0.71	0.81	-0.04	0.87	0.94	0.52	0.83	0.62	0.92	1.00

DISCUSSION OF PROPOSED MODEL OF FIRST RING ROAD

Proposed Model

In this section, we present a new model for evaluating the traffic flow on First Ring Road. The proposed model was built using a linear least square method with constraints. The linear least square was formulated by the problem of minimizing the difference between the calculated number of vehicles moving out of Ring Road and the corresponding measured number of outgoing vehicles. Observe that the number of vehicles entering at various intersections of Ring Road is obtained from measurement data. Then according to the locations of traffic intersections, the vehicles are accumulated on the ring road or the portions of vehicles are diverted by moving out of Ring Road. The number of vehicles moving out of Ring Road can be computed as follows.

The vehicles from roads flowing from twelve connecting roads travel along First Ring Road and finally move out of Ring Road (exits). Assume that I_1, I_2, ... I_n are the number of vehicles entering Ring Road and E_1, E_2, ..., E_n are the number of vehicles moving out of Ring Road. Vehicles are randomly passing out of Ring Road from exits. The fractions $r_2\,x_2$, $r_3\,x_3$,... $r_n\,x_n$ of vehicles that pass through exits where r_2, r_3,... r_n are random numbers. The values of x_2, x_3,..., x_n are computed in a way such that the following condition holds:

$$r_2x_2I_j + r_3x_3I_j + \ldots + r_nx_nI_j = I_j \tag{1}$$

for $j = 1, 2, \ldots, n$ which can be simplified as

$$r_2x_2 + r_3x_3 + \ldots + r_nx_n = 1 \tag{2}$$

Now, the general relation with input and output can be given as follows

$$r_2x_2\mathrm{I_n} + r_3x_3\mathrm{I_{n-1}} + \ldots + r_{n-1}x_{n-1}\mathrm{I_3} + r_nx_n\mathrm{I_2} = \mathrm{E_1} \tag{2a}$$

$$r_2x_2\mathrm{I_1} + r_3x_3\mathrm{I_n} + \ldots + r_{n-1}x_{n-1}\mathrm{I_4} + r_nx_n\mathrm{I_3} = \mathrm{E_2} \tag{2b}$$

$$\vdots$$

$$r_2x_2\mathrm{I_{n-2}} + r_3x_3\mathrm{I_{n-3}} + \ldots + r_{n-1}x_{n-1}\mathrm{I_1} + r_nx_n\mathrm{I_n} = \mathrm{E_{n-1}} \tag{2(n-1)}$$

$$r_2x_2\mathrm{I_{n-1}} + r_3x_3\mathrm{I_{n-2}} + \ldots + r_{n-1}x_{n-1}\mathrm{I_2} + r_nx_n\mathrm{I_1} = \mathrm{E_n} \tag{2n}$$

The above equations can be written in matrix vector format Ax = E.

$$\underbrace{\begin{bmatrix} r_2I_n & r_3I_{n-1} & & r_{n-1}\mathrm{I_3} & r_n\mathrm{I_2} \\ r_2\mathrm{I_1} & r_3\mathrm{I_n} & \cdots & r_{n-1}\mathrm{I_4} & r_n\mathrm{I_3} \\ \vdots & & & \vdots & \\ r_2\mathrm{I_{n-2}} & r_3\mathrm{I_{n-3}} & & r_{n-1}\mathrm{I_1} & r_n\mathrm{I_n} \\ r_2\mathrm{I_{n-1}} & r_3\mathrm{I_{n-2}} & \cdots & r_{n-1}\mathrm{I_2} & r_n\mathrm{I_1} \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} x_2 \\ x_3 \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix}}_{x} = \underbrace{\begin{bmatrix} E_1 \\ E_2 \\ \vdots \\ E_{n-1} \\ E_n \end{bmatrix}}_{E} \tag{3}$$

Note that the above system is over determined system which can only be solved using least square method using the constraint given in eq. (4). The constraints which have to be imposed is

$$x_i \geq 0 \tag{4}$$

for $i = 1, 2, \ldots n$. The model of the traffic flow on First Ring Road is solved using Algorithm 1 which uses the Matlab function *lsqlin*. The algorithm least square problem with the form

$$\min_{x} \frac{1}{2} \|Ax - E\|^2 \text{ subject to } Cx \leq d \tag{5}$$

can be solved using the function *lsqlin*.

$$x = lsqlin(A, E, C, d); \tag{6}$$

Algorithm 1 uses the number I_i of vehicles entering the ring road and the number E_i of vehicles exiting the ring road for $i = 1, 2, \ldots n$. The algorithm requires randomly generated number r_i in the range of [0, 1]. The output of the algorithm is the traffic distribution x_i along the roads intersecting with Ring Road. The algorithm first builds the matrix *A* of equation (3) and then the terms *C* and *d* of equation (5) are formulated. Then function (6) is used to compute *x*.

Algorithm 1: Solution to Proposed Model of First Ring Road

```
1  Input: incoming I and outgoing E number of vehicles and
   randomly generated number r
2  Output: fractions x of vehicles that moves out at each exit

3  For i =1 to n
     For j = 1 to n-1
     • Compute components of A using
     • A(i, j) = r(j+1) * I(k)
     • where k = mod(n-i+j, n);
     End (For)
4  Fnd (For)
5  C = -eye(n);
6  d = zeros(n, 1);
7  x = lsqlin(A, E, C, d);
```

Simulation Results and Discussion

The computational results from the simulation and the measured result are shown in Figures 8 to 12. The figures show the number of vehicles per 15 minutes interval moving out of different roads from 8:00 to 21:00 H. Two plots are made in each figure where the number of vehicles moving out of ring road obtained from simulation of computational model and the measured number of vehicles using machines are shown. These results demonstrate good agreements between simulation and measured data. Observe that Figures 8 and 12 show quite good results. Figures 9 - 11 provide some reasonable results due to the random pattern of vehicle movements. The parameters identified from simulation can be later used to predict vehicle movements in Ring Road.

Daily readings taken once per week cannot be relied on for solid conclusion. Students' timetable was another shortcoming to this study. Students were not able to cover all day traffic limiting the data collection to limited hours of the day compared to other data that was taken automatically. Despite the fact that the study was performed during a short period of time that may not indicate the real behavior of the traffic over the whole year, it provides a clear insight of traffic flow behavior. However, we recommend that more data for the same time periods to be taken to consolidate the findings.

A general observation that was drawn from the study is that all streets follow the same pattern in terms of traffic behavior despite the difference in their traffic volume. The fact that some roads are located close to each other (within about 450-600 m) and flowing into the same direction resulted in high volume of traffic within some portions of Ring Road. When pedestrians' main crossing areas are added to the mentioned case, the traffic problem will increase. The study revealed the streets with high and low volume of traffic, area design deficiencies, and the need for some rearrangements to the area in order to ease the traffic congestion. Implementation of such measures should not be delayed since the number of vehicles is escalating annually.

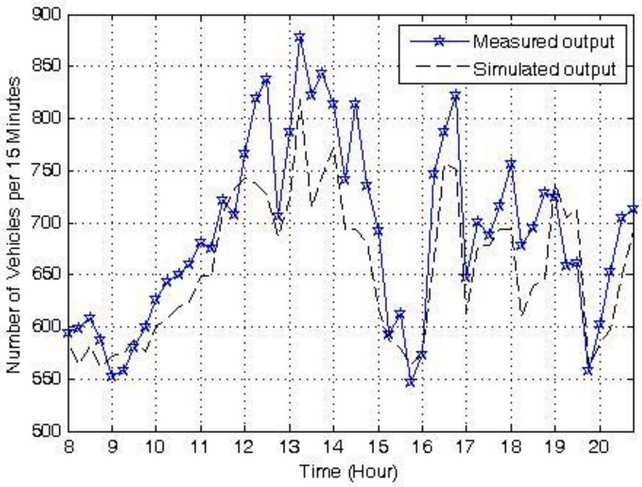

Figure 8. Average number of vehicles travelling over different days from 8:00 to 21:00 at King AbdulAziz Road

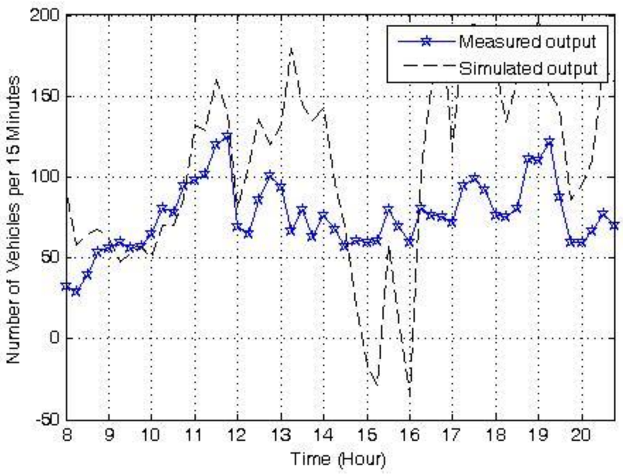

Figure 9. Average number of vehicles travelling over different days from 8:00 to 21:00 at King Fahd exit (Ramp)

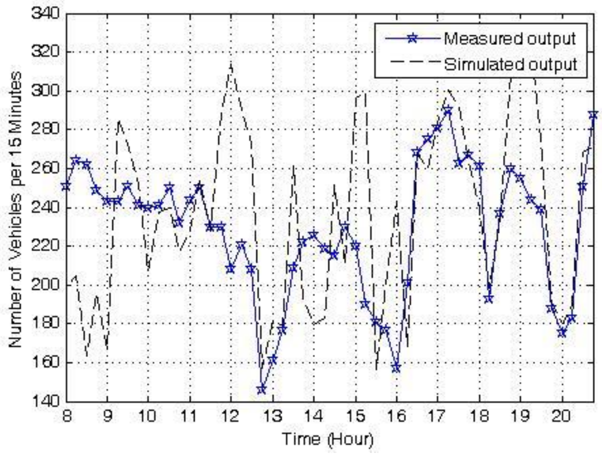

Figure 10. Average number of vehicles travelling over different days from 8:00 to 20:45H at King Fahd Road

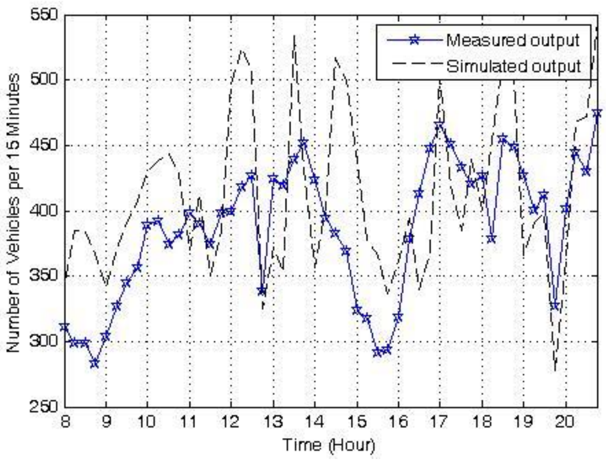

Figure 11. Average number of vehicles travelling over different days from 8:00 to 21:00 at Abu Bakr Road

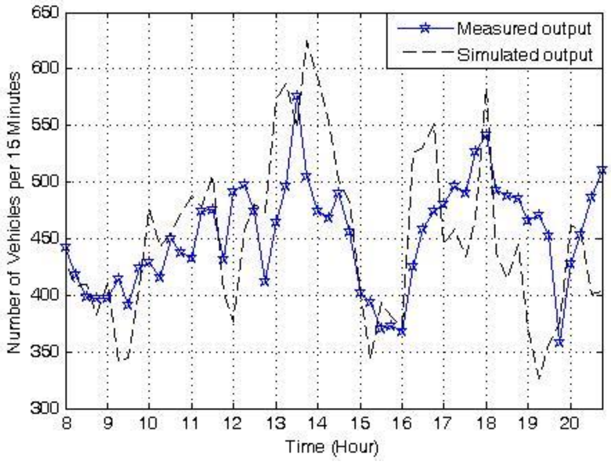

Figure 12. Average number of vehicles travelling over different days from 8:00 to 21:00 at Omar Ibn Al-Khattab Road

Some steps and regulations, if taken, would help alleviate the traffic congestion problem faced at First Ring Road. Regulating the traffic flow from all roads to the area would help restricting the flow to a certain number per time period. This can be achieved by installing traffic lights in the area right before the ring road. If these lights are synchronized to allow certain number of vehicles, it will limit the number of vehicles on the ring road to a certain acceptable capacity. Information and communication technology can play a significant role in reducing the traffic congestion such as electronic boards, a local radio channel to broadcast traffic news and sending SMS messages to mobile phones within the city and GPS systems. The area represents almost the only link among different directions. Users of these roads are forced to go through the area if they want to cross from one direction to other direction. Although, it might be expensive, bridging over the area may solve most of the problem.

CONCLUSION

In this work, traffic movement on the ring road around Al-Masjid Al-Nawabi which experiences intense traffic especially during Hajj and Umrah seasons was chosen as a case study. Traffic movement data was collected from manual counting and machine measurements. To understand the traffic behavior, the data were analyzed and verified using statistical analysis. A computational model for the traffic distribution along the roads intersecting with First Ring Road was built using linear least squares method with constraints. The linear least square problem was formulated by minimizing the difference between the measured number of vehicles and the sum of numbers of vehicles from all entrances of Ring Road that move out at each road. A simulation program for the computational model was developed using Matlab. This program uses the number of vehicles at each entry of the ring road obtained from measurement data and produces the number of vehicles moving out of each exit of the ring road. The simulation results show good agreements with the measured number of vehicles at each road intersecting with Ring Road. Thus the model can be used as a prediction model of vehicle movements. Finally, the analysis and the model can substantially replicate the traffic behavior on First Ring Road.

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