Evaluation and Improvement of Traffic Operation At Kahtan Square in Baghdad city

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الخلاصة

إنّ التقاطعات (الساحات) تعتبر أجزاء مهم من منظومة الطريق . الطاقة التشغيلية ، الاستيعابية ، الأمان والكلفة تعتمد بشكل كبير على تصميمِ التقاطع (الساحات) و خصوصاً في المناطق الحضرية.
تتضمن أهداف الدراسة الحالية التحليلِ ،تقييم وتحسينِ قابلية التشغيل للمرور في الساحة المختارة (ساحة قحطان) في مدينةِ بغداد وذلك بتحليل واستعمال العديد من المقترحات لتحسينِ قابلية التشغيل للمرور في ساحة قحطان عملية تحت الظروف الحالية التي تعمل بها الساحة في الظروف الحاليةَ و تقديم أفضل مقترح للوصول إلى أحسن قابلية تشغيل في الساحة.
للوصول إلى هذه الأهداف، تم جمع الحجوم المرورية والتخطيطَ الهندسي لساحة قحطان المطلوبة لغرض التحليل المروري والهندسي للتقاطع تم جمعها يدويا ، بينما برنامج المرور SIDRA استخدم لمتطلبات التحليل المروري.
لقد تم استنتاج أن تنفيذ مجسر يربط بين حركة المرور الرئيسية (البياع ومستشفى اليرموك) في ساحة قحطان يكون هو الاقتراح الأفضل لتحسين الاستيعابية وعملية تشغيل المرور في ساحة قحطان.

Abstract :

The intersections "roundabout" is an important part of the highway system. The operational efficiency, capacity, safety and cost of the system depend largely upon its design of intersection "roundabout", especially in urban areas.
The objectives of the present study include the analysis, evaluation and improvement the operation traffic of selected roundabout (Kahtan Square) in Baghdad city by analysis and use many alternatives to improve the roundabout (Kahtan Square) operation under local exist conditions and to present a best proposal to enhance the performance at the required facility.
To achieve these objectives, the traffic volumes data collection and geometric layout for Kahtan square that required for the traffic and geometrical analysis were gathered manually, while SIDRA traffic program is used for the requirements of traffic analysis process.
It has been concluded that, fly over at the main path of traffic movement at kahtan square (Baya'a – Yarmok hospital) is the best proposal to improve the capacity and traffic operation for kahtan square.

Keywords: Traffic operation, Round about, Level of service, Capacity

Introduction

The concept of capacity, level of service and delay are central to the analysis of intersections, as they are for all types of facilities, therefore that both capacity and level of service must be fully considered to evaluate the overall traffic operation of the intersections [1] . While The delay is one of problems that occur in any facility of traffic where the delay is defined as " the additional travel time experienced by a driver , passenger ,or pedestrian ". The primary factors that affect delay are lane group volume and lane group capacity. [2]

Kahtan square is located on the principle arterial street that represents one of the significant roads in Baghdad city for the following reasons:

1. This arterial street connects between Baghdad centre with the west and south parts of Iraq. Therefore, this path forms one of the main roads towards Baghdad city and represent by Baghdad-Hilla street.
2. The road where kahtan square located represents the main road that connects a significant districts e.g. Al-Baya'a districts, which is, occupy a large zone from Baghdad area.
3. Kahtan square located closely to Al-Qadisyah expressway.

The previous mentioned factors, in addition to other factors such as; the closely location of Al-Mustansiriyah university/medical college and Al-Yarmok hospital to kahtan square produce the existing high traffic volume and, high congestion due to the limited flow capacity as compare with the existing traffic volume. The figure No.1 show the kahtan square location.

Figure (1): Satellite Image of Kahtan Square

Objective of study

The main objectives of the present traffic study are:
1. The calculation of the existing LOS at roundabout (Kahtan Square) to evaluate traffic operation.
2. Preparation of the best alternative at roundabout (Kahtan Square) to achieve a suitable LOS at the present time and during the design period.

Background:

A roundabout can be defined as "a circular traffic intersection featuring yield control on all entering legs, one-way continuous flow within the circulatory roadway, channelization of approaches, and appropriate geometric curvature to keep circulating speeds low [3]. The currently available methods of roundabout analysis have various theoretical underpinnings. The discussion below describes some of the key operational parameters of the methods:

HCS. The methodology of the 2000 *Highway Capacity Manual* (HCM), implemented in the HCS program. It uses two parameters to compute roundabout operations (in addition to the circulating conflicting volume): [4]

1.*Critical Gap* (tc), which is defined as the minimum time interval in the circulating traffic stream that allows one vehicle to enter the roundabout. A typical driver would enter the roundabout when faced with any gap equal to or greater than the critical gap. Increasing the critical gap decreases approach capacity.

2.*Follow-up Time* (tf), which is defined as the time between the entry of one vehicle into the roundabout and the entry of the next vehicle using the same gap in circulating traffic, under a condition of continuous queueing on the roundabout approach. In other words, the follow-up time is equal to the inter-vehicle headway on an approach at capacity.

SIDRA. the SIDRA software, based on methodology developed in Australia, also uses a gap acceptance approach to model roundabout operations. Key parameters used in the SIDRA methodology include: [5]

1. *Critical Gap*, which is essentially identical to the tc parameter from the HCM methodology.
2.*Follow-up Headway*, which is essentially identical to the tf parameter from the HCM methodology.
3. *Intra-bunch Headway*, which relates to platooning in the circulating stream.
4. *O-D factor*, which accounts for differing characteristics of circulating traffic depending on the leg of origin.

Methodology

The steps required to perform a roundabout intersection analysis are identified below -

- AM Peak Hour traffic volume count and determine PHF
- Studying the current conditions under present traffic volume
- Investing and selection for the best alternative in this improvement.
- Determinate level of service for the improved facility.
- Comparison of the above options and recommendation

Study Area layout :

The existing situation to control the traffic movement at kahtan square is carry out through the control of police men, where there is not less than three to four police men at this square to arrange the traffic movement at the PHV. This process reflects the highest traffic volume at the square. As previously mentioned, the existing location of Al-Yarmok hospital has a badly effect on the traffic movement in addition of the existing on street parking which result a noticed decrease in the flow capacity. Also the closely location of the railroad to kahtan square (about 250 m) results a bad effect on the efficiency of the flow capacity.

Data Collection

A. Traffic volume:

The traffic account is carry out at kahtan square from (7:00 am to 7:00 pm) during the workday of the week from (17-July to 28-July), 2005 and the highest recording traffic volume in each direction is recorded to be used in the analysis of the present study.

The vehicles are classified into two types:

1. Small vehicles: any vehicles move on four wheels includes the PC.
2. Large vehicles: any vehicles move on more than four wheels.

This type of vehicle is converted to passenger car by using (PCU) factor equal to (2.0).The international specification concerning the traffic engineering and the geometrical design should be consider the future forecasting of the growth in the traffic. In addition, the DHV that could be used in the analysis is the highest 30th hourly volume during the year, but regarding the limited available period to prepare the study, it has proposed to carry out the traffic amount during five-work day from Sunday to Wednesday and select the highest traffic volume.

Table (1) appears the highest account traffic volume in each direction for every (15 min.) from (7:00 am to 7:00 pm). The Figure (2) presents all the volume movement those mentioned in Table (A-1) see Appendix A.

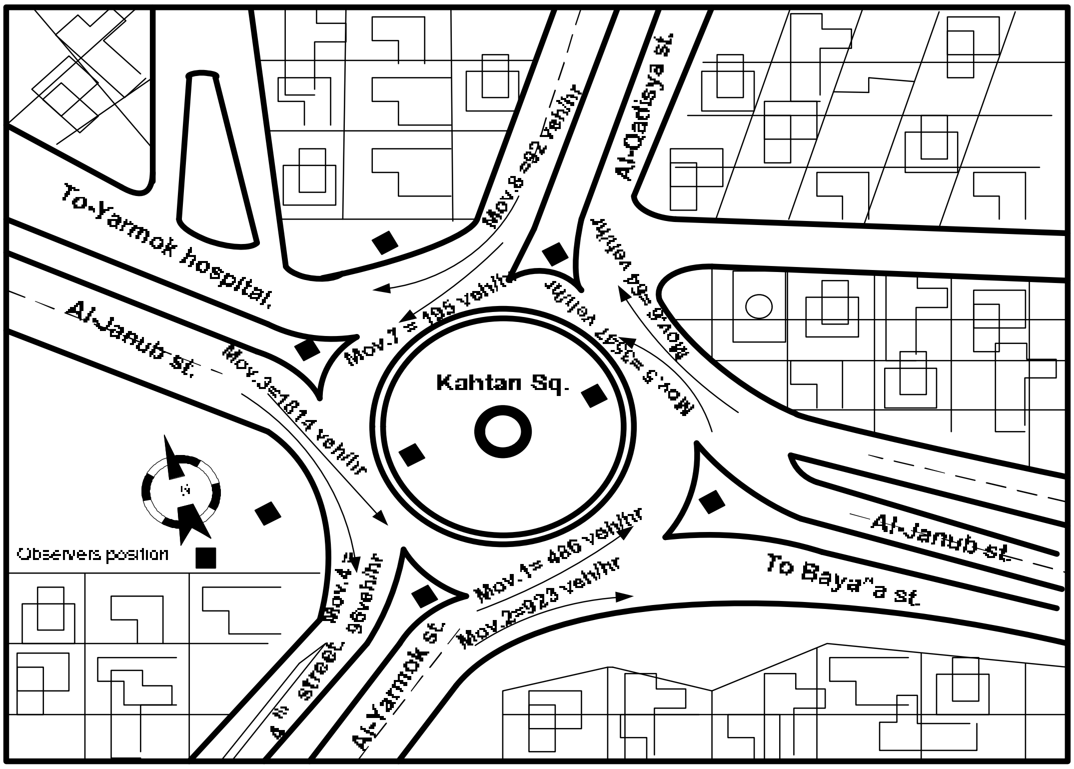

Figure (2) traffic volume at Khaten square at base year (2005)

B. Geometrical Data:

Table (1) clear existing geometric design, numbers of lane and lane width are represents significant international factors for the preparation of any intersection traffic study. Therefore, any submitted proposal should be match with the existing geometrical shape and the available area closely to the specific location.

Note: The diameter of round square = 100m

Table (1) Geometric characteristics for Kahatan round about Intersections

Approach Direction.	*Number of lanes*	*Width of lane (m)*
Arrival from AL-Baya'a	**3**	**3.5**
Arrival from Al-Yarmok Hospital	**2**	**3.5**
Arrival from the 4th street –Al-Yarmok	**4**	**3.5**
Arrival from Al-Qadisiyah street	**2**	**3.5**

Analysis and Results,

SIDRA program was applied in this study for the requirements of evaluating and analyzing the roundabout intersections, the following parameters were calculated;

- Degree of saturation
- Average delay

- Practical spare capacity
- Level of service (LOS)

The Appendix B show samples from SIDRA out put program

1.Determine Peak hour volume:

The traffic account every 15 min. is carried out from 7:00 am to 7:00 pm as shown in Figure (3). The PHV is found to be between (8.0 to 9.0 a.m) as shown in Figure (4) , where the number of vehicles accounted to be equal to 7500 veh./hr and distributed as per the following composition:

3800 veh./hr **(Arrival from Al-Baya'a)**
1900 veh./hr **(Arrival from Al-Yarmok hospital.)**
1400 veh./hr **(Arrival from the 4th street-Al Yarmok)**
400 veh./hr **(Arrival from Al-Qadisya street)**

Calculation of the PHF (Peak Hour Factor):

The peak hour factor is defined as the ratio of total hourly volume to the maximum 15-min rate of flow within the hour as following equation (HCM):.

$$\textbf{PHF} = \frac{Hourly\ \ volume}{peak\ rate\ of\ \ flow\ (within\ hour)}$$

$$\textbf{PHF} = \frac{Hourly\ \ volume}{4 * \mathrm{V15\,min}}$$

Where:-

PHF= Peak-hour factor

$\mathbf{V_{15}}$= Volume during the peak 15 min of the peak hour, on veh/15min

Depending on the traffic volume data, the PHF is calculated in each direction, table (2) presents the results during the PHV.

Table (2): PHF Values at Kahtan Square

Direction	PHF
Arrival from AL-Baya'a	0.96
Arrival from Al-Yarmok Hospital	0.93
Arrival from the 4th street –Al-Yarmok	0.95
Arrival from Al-Qadisiyah street	0.91

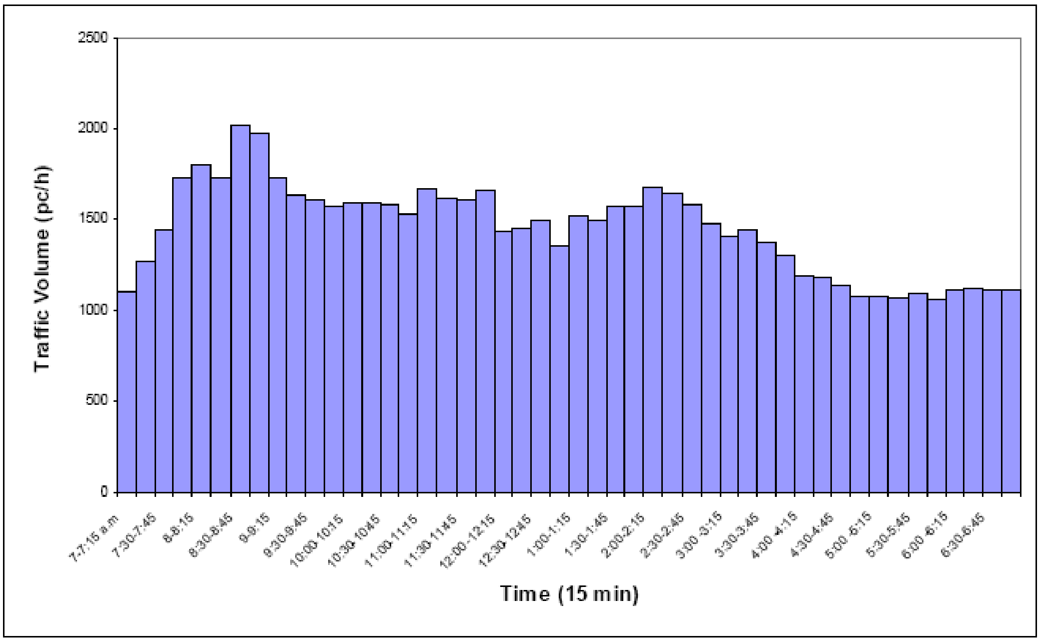

Figure (3) variation of traffic volume during the daily hours at kahtan square

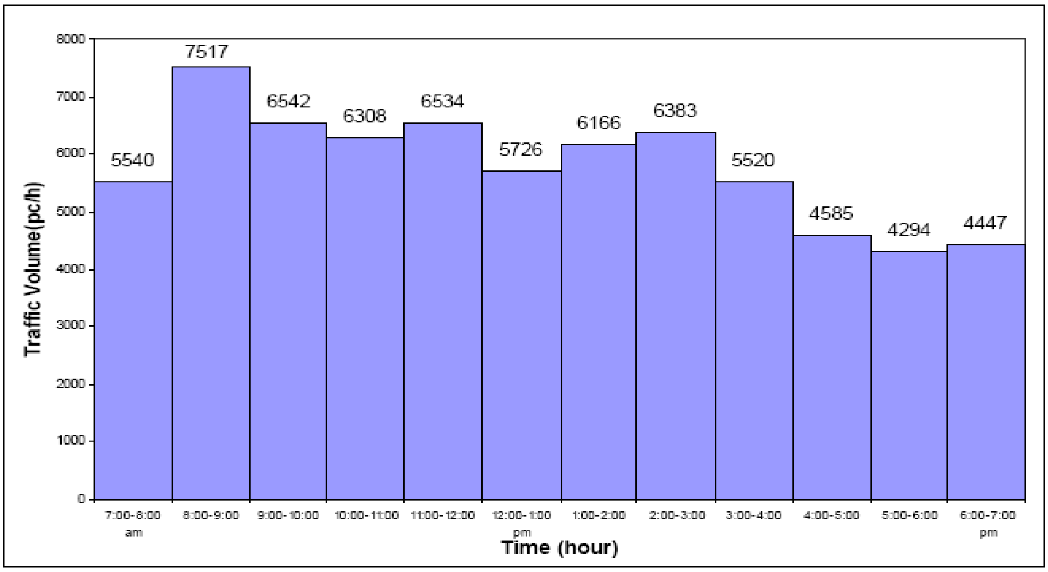

Figure (4) Distribution of traffic volume during the PHV at Kahtan square

2. Saturation Flow:

For the purposes of the preparation of technical data that required for the theoretical calculation, the saturation flow for each lane consider to be one of the significant and sensitive factor in this study, due to its direct effect on the average delay at the intersection which represent the main indication to determine the LOS at the intersection [4].

Webster's method is followed to calculate the lane saturation flow in each direction. [6]. Table (3) presents the average saturation flow at kahtan square.

Table (3): Actual saturation flow at kahtan square

Direction	Saturation flow (pc/hr/lane)
Arrival from Al-Baya'a	**1600**
Arrival from Al-Yarmok hospital	**1550**
Arrival from 4thstreet (Yarmok)	**1500**
Arrival from the service road (express way)	**1550**

3.Existing Average Delay and level of service at Kahtan Square:

The existing LOS at kahtan square found to be very low, where the traffic volume is too high as compare with the actual flow capacity. The degree of saturation at kahtan square found to be more than **(1.05)** and according to the international specification the rate of increase in delay will be high due to the fact that relation ship between the degree of saturation and the average delay is nonlinear.

The existing traffic movement at kahtan square is arranged by police men at the peak hour volume. Accordingly, it's operate closely like the case of vehicle actuated which is controlled by traffic signals. The existing congestion level at kahtan square is too high especially during the peak hour volume. Therefore, it is too difficult to calculate the average delay by using of any recommended method e.i. the (HCM) method required the following information to calculate the average delay:

1. The arrival time for each vehicle.
2. The departure time for each vehicle.
3. The difference between the arrival and departure time (for each vehicle).

The calculation of the above mentioned information is impossible because the queue of vehicles is too long. In general if the degree of saturation more than (90%), it is difficult to calculate the average delay at the site directly.

Accordingly, the calculation of average delay for a random sample of vehicles in each direction during PHV is proposed in table (4).

Table (4): Actual average delay at kahtan square

Direction	Average delay (sec/veh)	No. of Trials
Arrival from Al-Baya'a	315	15
Arrival from Al-Yarmok hospital	210	15
Arrival from 4thstreet (Yarmok)	35	15
Arrival from the service road (express way)	45	15

Table (4) presents the actual average delay at kahtan square. It is appear that the LOS for the both main directions (arrival from Al-Baya'a and from Al-Yarmok hospital) is LOS (F) according to HCM method as following

Level OF Service(LOS)	Average Delay(Sec)
A	**<10**
B	**> 10-20**
C	**> 20-35**
D	**>35-55**
E	**>55-80**
F	**>80**

4. Design Alternatives

Alternative NO.1- (signalized 4-leg intersection)

This alternative include the replacement of the existing roundabout by a signalized 4-leg intersection with providing the higher possible number of lane in each direction and occupying the available area as presented in Figure (5).

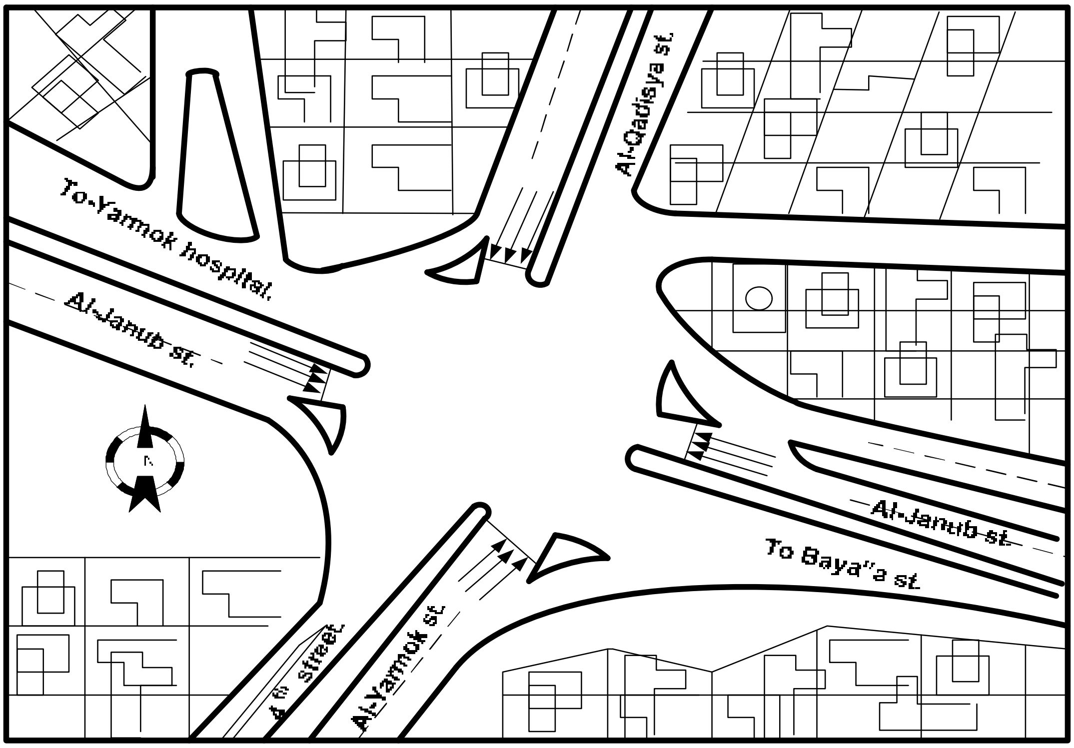

Figure (5) Alternative No.1 at Kahtan square

The analysis of this alternative appears that Kahtan intersection will be operating at (LOS F). The LOS's results of this proposal are presented in Table (5). Table (6) shows the values of the factors affecting performance at Kahtan square. While the analysis of the data for the target year (After 20 year) appears that the LOS is too low as obvious in Table (7).Table (8) shows the values of the factor affecting performance on the target year.

Table (5) :LOS's Results of Alternative No.1 at the base year.

Direction	Degree of saturation	Average delay	LOS
Arrival from Al-Baya'a	1.04	141.3	F
Arrival from Al-Yamork Hospital	1.03	165.2	F
Arrival from 4-th street Al-yamork	0.95	164	F
Arrival from Al-Qadisiyah street	0.43	53.8	E

Table (6) :- Factors affecting performance of kahtan square (Alternative No.1 for base year)

Factor	Value
Average delay	147.5(sec/Veh)
Stop rate	1.7
Performance index	785.85
Total delay	247.56
Practical spare Capacity	-14%

Table (7) Los's at kahtan square for the target year.

Direction	Degree of saturation	Average delay	LOS
Arrival from Al-Baya'a	1.76	1405.	F
Arrival from Al-Yamork hospital	1.8	1501.3	F
Arrival From the 4-th Street –Al-Yarmok	1.54	1091.7	F
Arrival from Al-Qadisiyah Street	0.619	53.2	E

Table (8) : Factors affecting performance at Kahtan Square (Alternative No.1) for the target year.

Factor	Value
Average delay	1365.1(sec/veh)
Stop rate	6.57
Performance index	7349.19
Total delay	4124
Practical spare Capacity	-50%

Alternative No 2:

Any alternative (proposal) include the improvement of geometric design at kahtan square will not lead to enhance the traffic movement due the high difference between actual traffic volume and a flow capacity. Therefore, the unique engineering solution is to execute the **fly over** on the main path of traffic movement (from Al-Yarmok hospital- Through kahtan square-toward Al-Baya'a) as shown in Figure (6). Accordingly and through out the calculated traffic volume during the PHV, the expected traffic volume on the proposal fly over is as follows:

Arrival from Al-Baya'a towards Al-Yarmok hospital (1550 pc/hr).

Arrival Al-Yarmok hospital towards Al-Baya'a (1500 pc/hr).

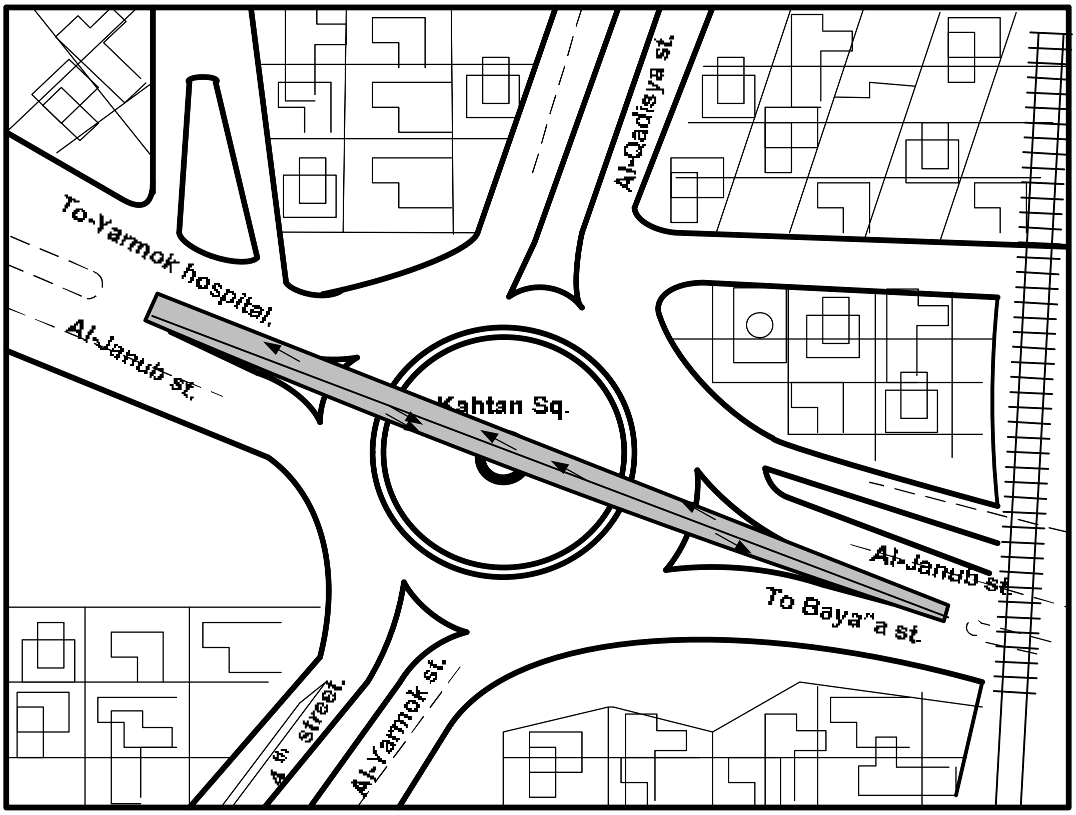

Figure No.(6) Alternative No.2 at Kahtan square

From the expected traffic that will use the proposed flyover, the required number of lanes can be estimated as per the U.S specification as below :

<u>Arrival from Al-Baya'a to Al-Yarmok Hospital</u>:

<u>Base Year</u>:

LOS = C.
Speed = 50 MPH.
(V/C) = 0.67.
SF = 1550 pc/hr.
CJ = 2000 pc/hr.
fw = 0.83.
fp = 1.0.
fHv = 1.0.
N = {1550 / (2000*0.67*0.83*1.0*1.0)} = 1.39 lane say two lanes.

<u>Target year:</u>

LOS = D.
(V/C) = 0.8.
CJ = 2000 pc/hr.
N = {2790/ (2000*0.8*0.83*1.0*1.0)} = 2.1 lane …say 2 lanes.

Therefore, use two lanes.

<u>Arrival from Al-Yarmok Hospital to Al-Baya'a</u>:

<u>Base Year</u>:

LOS = C.

Speed = 50 MPH.

(V/C) = 0.67.

SF = 1500 pc/hr.

CJ = 1900 pc/hr.

fw = 0.83.

fp = 1.0.

fHv = 1.0.

N = {1500/(2000*0.67*0.83*1.0*1.0)} = 1.34 lane say 2 lanes.

<u>Target year</u>:

LOS = D.

Speed = 50 MPH.

(V/C) = 0.8.

SF = 2700 pc/hr.

CJ = 1900 pc/hr.

fw = 0.83.

fp = 1.0.

fHv = 1.0.

N = {2700/ (2000*0.8*0.83*1.0*1.0)} = 2.03lane say two lanes.

Therefore, use two lanes.

From the analysis results to determine the required number of lanes it is concluded that, the required number of lanes for overpass will be as follows:

Direction	Required no. of lanes
Arrival from Al-Baya'a to Al-Yarmok Hospital	2
Arrival from Al-Yarmok Hospital to Al-Baya'a	2

According the analysis results for the fly over, the congestion at the at-grade intersection is checked and the results are present as follows:

<u>At base year:</u>

The proposed design for the at-grade intersection atkahtan square is to execute the signalized roundabout as shown in Figure (7), where the traffic analysis for this proposal results the (LOS C) at the base year as shown in Table (9).While Table (10) presents the factors affecting on the LOS results at the intersection.

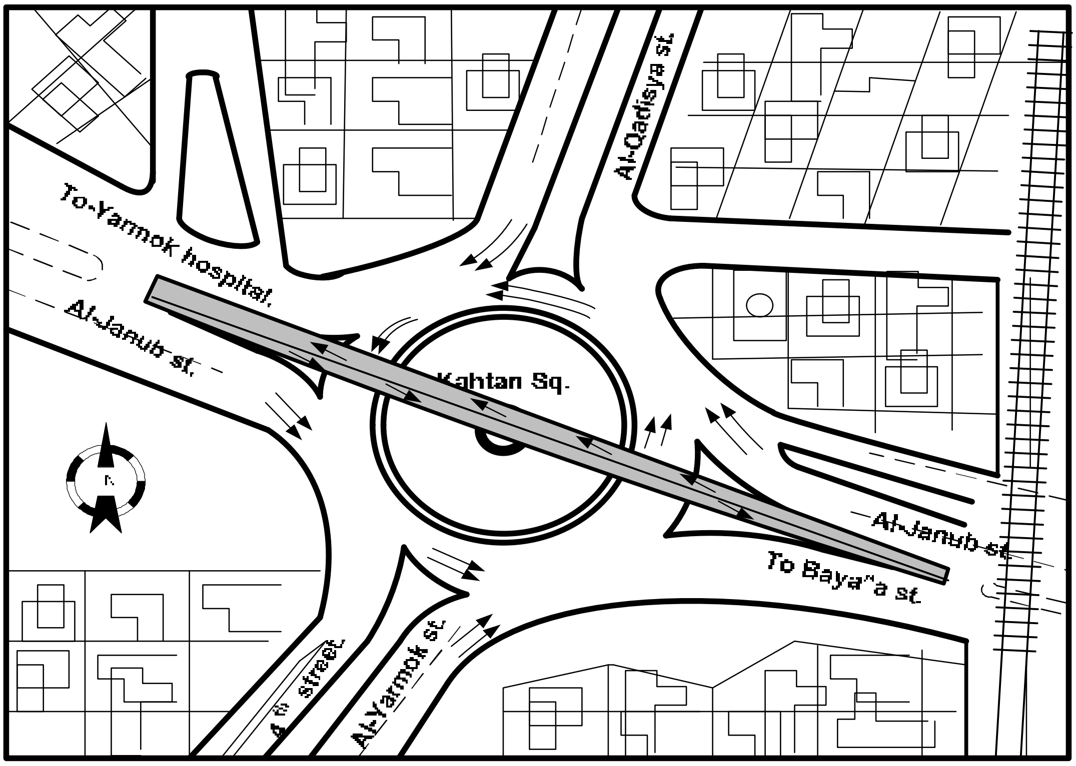

Figure No.(7) Alternative No.2 at kahtan square with signalized roundabout

Table (9) Los at kahtan square for the base year

Direction	Degree of saturation	Average delay	LOS
Arrival from Al-Baya'a	0.51	8.4	B
Arrival from Al-Qadisiyah Street	0.28	20.9	C
Arrival from Al-Yarmok Hospital	0.12	6.6	B
Arrival from the 4-th street Al-Yarmok	0.51	21.7	C

Table (10) : Significant factors affecting LOS's at Kahtan square

Factor	Value
Average delay	11.4(seclveh)
Stop rate	0.63
Performance index	93.16
Total delay	8.72
Practical spare capacity	75%

Target year:

The expected traffic volume at kahtan square on the target year is presented in Figure (8), knowing that the growth rate is assumed to be (3%). According to the calculated traffic volume, the LOS will be as presented in Table (11), while Table (12) presents some of significant factors affecting LOS on the intersection. These results shown that the LOS is (C), which is accepted according to the international specifications.

Table No.(11) LOS at Kahtan Square on the Target year

Direction	Degree of saturation	Average delay	LOS
Arrival from Al-Baya'a	0.786	11.5	B
Arrival from Al-Qadisiyah Street	0.432	24.2	C
Arrival from Al-Yarmok Hospital	0.19	5.4	B
Arrival from the 4-th street Al-Yarmok	0.795	37	D

Table No .12 : significant factors affecting LOS's at Kahtan square on the target year

Factor	Value
Average delay	16.2(seclveh)
Stop rate	0.74
Performance index	198.33
Total delay	22.2
Practical spare capacity	13%

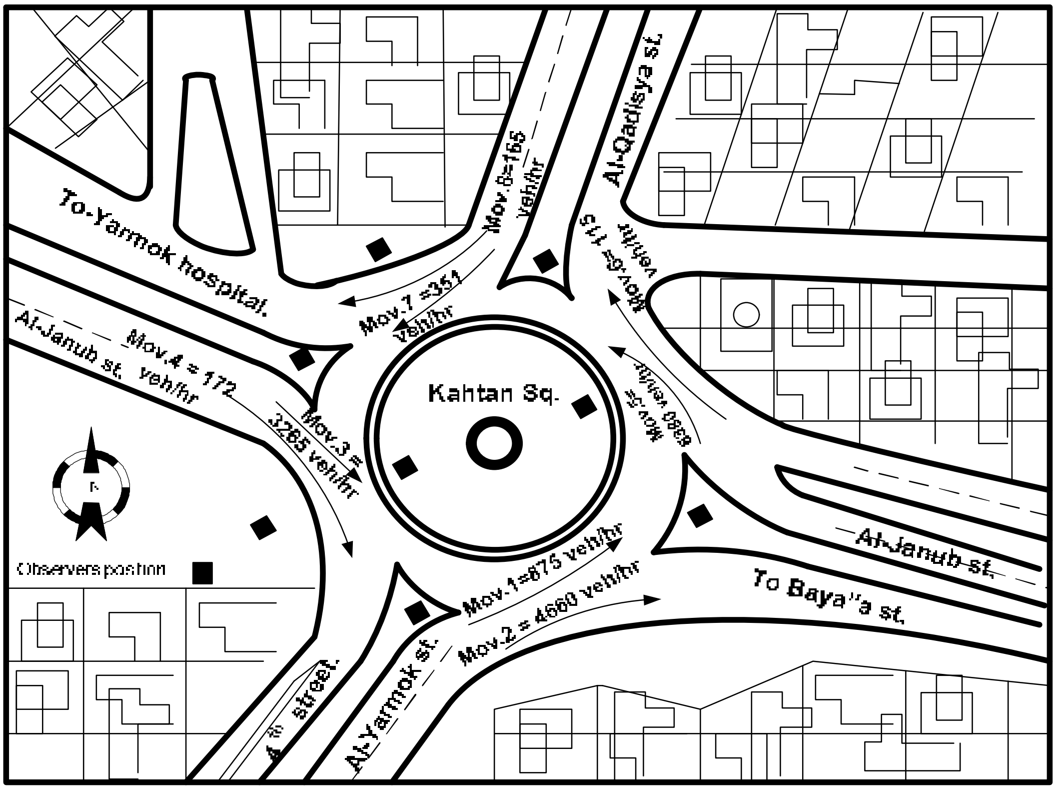

Figure No (8)the traffic volume at khatan square for target year

Alternative No.3:

This proposal is the same as proposal No.2, the difference only in the operation of the roundabout. In this proposal the roundabout assumed to be unsignalized as in the existing situation. The Australian specification is applied in the analysis process of this proposal as shown below:

ye = {(yc * e{(-yc* T) / 3600}) / (1- e{(-yc* To) / 3600})}

Where

ye: Entry capacity (pc/hr/lane).

y_c: Circulating flow (pc/hr).

T: Critical acceptance gap.

T_o: follow up gap.

Table (13) present the performance of the unsignalized roundabout at the base .The results seems to be accepted while Table (14) present the performance at the target year .The performance of the roundabout on the target year seems to be rejected as per the values of the reserve capacity.

Table (13) The performance of the unsignalized round about on the base year

Approach	Circulating flow (pc/hr)	Entry Capacity (pc/hr)	Entry flow (pc/hr)	Reserve Capacity (%)
From Al-Baya'a	835	2667	1061	151
From Al-Qadisiya	1575	1407	387	263
From Al-yarmok Hospital	1885	1071	410	161
From 4-th street	640	3150	1404	132

Table (14) The performance of the unsignalized round about on the Target year

Approach	Circulating flow (pc/hr)	Entry Capacity (pc/hr)	Entry flow (pc/hr)	Reserve Capacity (%)
From Al-Baya'a	1503	1500	1910	**-27%**
From Al-Qadisiya	2835	459	697	**-51%**
From Al-yarmok Hospital	3393	276	738	**-167%**
From 4-th street	1152	2034	2536	**-24%**

CONCLUSIONS AND RECOMMENDATIONS

The Roundabout intersection (Kahtan Square) under discussion is presently operating at an unacceptable level of service for both main directions (arrival from Al-Baya'a and from Al-Yarmok hospital) .

Regarding the analysis results of this study, the following are recommended:

1. Execution of the fly over at the main path of traffic movement at kahtan square (Baya'a – Yarmok hospital). This fly over contain two lanes for each direction.
2. Apply the proposed geometric design (Proposal No.2) at-grade signalized roundabout as shown in Figure (7) this improvement enhanced the operation of the intersection and increase the flow capacity to its high value to achieve an acceptable LOS on the target year.

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Appendix A

Table (A-1) Traffic volume at Kahtan square from 7:00 a.m to 7:00 p.m

	mov. 1	mov. 2	mov. 3	mov. 4	mov.5	mov. 6	mov. 7	mov. 8
7:00-7:15 a.m	56	147	275	13	550	9	40	14
7:15-7:30	77	172	301	15	624	11	51	18
7:30-7:45	89	198	322	21	712	17	62	16
7:45-8:00	121	235	397	24	845	23	64	21
8:00-8:15	117	243	415	25	875	21	76	31
8:15-8:30	113	230	435	20	852	17	70	23
8:30-8:45	129	235	477	22	922	14	81	21
8:45-9:00	127	215	487	29	898	12	68	17
9:00-9:15	138	251	389	32	813	20	70	11
9:15-9:30	129	240	401	31	745	19	59	13
9:30-9:45	113	245	375	28	755	17	61	13
9:45-10:00	99	255	369	23	749	14	49	16
10:00-10:15	96	239	433	21	732	15	42	17
10:15-10:30	91	241	421	17	753	9	51	11
10:30-10:45	98	207	435	19	735	14	62	17
10:45-11:00	89	191	429	21	717	18	52	15
11:00-11:15	102	189	388	25	868	13	59	18
11:15-11:30	95	208	412	20	792	17	49	20
11:30-11:45	107	184	425	23	779	9	59	16
11:45-12:00	99	188	407	19	860	14	61	19
12:00 -12:15	89	169	445	18	625	10	60	12
12:15-12:30	96	174	440	22	633	14	51	16
12:30-12:45	104	164	556	17	578	12	43	16
12:45-1:00	85	155	492	21	538	9	49	13
1:00-1:15	94	180	517	22	635	16	17	14
1:15-1:30	82	174	492	27	629	15	59	12
1:30-1:45	92	169	572	19	662	9	42	13
1:45-2:00	85	184	544	28	650	14	54	14
2:00-2:15	82	179	612	23	714	17	39	10
2:15-2:30	79	192	584	27	692	11	47	14
2:30-2:45	74	177	562	18	676	19	49	15
2:45-3:00	77	165	507	25	632	20	42	13
3:00 -3:15	62	194	449	18	621	15	36	12
3:15-3:30	65	182	427	26	665	26	39	10
3:30-3:45	70	167	459	16	594	13	41	11
3:45-4:00	68	154	417	21	572	15	42	13
4:00 -4:15	59	159	382	14	517	17	30	11
4:15-4:30	58	166	364	22	506	19	39	9
4:30-4:45	66	148	355	17	482	16	41	12
4:45-5:00	58	146	323	19	475	11	33	11
5:00 -5:15	64	140	312	23	479	7	41	14
5:15-5:30	60	152	321	29	443	11	38	11
5:30-5:45	69	145	334	20	450	9	49	12
5:45-6:00	71	138	317	26	436	8	51	14
6:00 -6:15	77	149	341	32	438	12	49	11
6:15-6:30	69	162	328	29	465	10	45	13
6:30-6:45	74	159	319	24	476	8	39	8
6:45-7:00 pm	78	170	301	28	459	15	42	17

Appendix B

- **Summary of analysis steps Intersection Performance under exist condition (table s-0 to s-15)**

Cycle Time = 120

Table S.0 - TRAFFIC COMPOSITION DATA

(Flows in veh/hour as used by the program)

Mov No.	Left		Through		Right	
	LV	HV	LV	HV	LV	HV
10	0	0	3547	0	0	0
11	0	0	195	0	0	0
12	0	0	1814	0	0	0
13	0	0	486	0	0	0

Based on unit time = 60 minutes. Flow scale and PHF effects included (if any).
Slave movement flows are included in master movement flows.

Table S.1 - MOVEMENT PHASE AND TIMING PARAMETERS

Mov No.	Mov Typ	PHASE MATRIX First Green Fr	To	Op	Pr	Second Green Fr	To	Op	Pr	Lost Tim 1st Grn	Lost Tim 2nd Grn	Req.Mov.Time 1st Grn	Req.Mov.Time 2nd Grn	Eff. Grn 1st Grn	Eff. Grn 2nd Grn
10	T	*1	2							3		72.5		60	
11	T	*2	3							3		11.0Min		8	
12	T	*3	4							3		38.6		31	
13	T	*4	1							3		12.5		9	

1

Table S.2 - MOVEMENT CAPACITY PARAMETERS

Mov No.	Arv Flow (veh /h)	Satn Flow 1st Grn	Satn Flow 2nd Grn	Flow Ratio 1st Grn	Flow Ratio 2nd Grn	Total Cap. (veh /h)	Prac. Deg. Satn xp	Prac. Spare Cap. (%)	Lane Util (%)	Deg. Satn x
10 T	3547	6800		.522		3400	.90	-14	100	1.043*
11 T	195	6800		.029		453	.90	109	100	.430
12 T	1814	6800		.267		1757	.90	-13	100	1.033
13 T	486	6800		.071		510	.90	-6	100	.953

1

Table S.3 - INTERSECTION PARAMETERS

Crit Mov No.	Green Period	Phases Fr	Phases To	Adjusted Lost Time,l	Adjusted Flow Ratio	Required Grn Time Ratio	Required Movement Time
10 T		1	2	3	.522	.580	72.5
11 T		2	3	11	-	-	11.0Min
12 T		3	4	3	.267	.296	38.6
13 T		4	1	3	.071	.079	12.5
			Total:	20	.860	.955	134.6

- Flow ratio not used for cycle time calculations and the adjusted lost time equals the required movement time

(=Min or Max as shown in Table S.1)

Cycle Time:

Minimum	Maximum	Practical	Chosen
44	120	120	120

(Cycle time specified by the user)

Degree of Saturation (Highest) = 1.043
Practical Spare Capacity (Lowest) = -14 %
Total Vehicle Flow = 6042
Total Vehicle Capacity (all lanes) = 6120

Table S.4 - PHASE INFORMATION

Phase No.	Change Time	Green Start	Displayed Green	Grn+Intgrn Secs	Prop.
1	0	5	58	63	.525
2	63	68	6	11	.092
3	74	79	29	34	.283
4	108	113	7	12	.100

1

Cycle Time = 120

Table S.5 - MOVEMENT PERFORMANCE

Mov No.	Total Delay (veh-h/h)	Aver. Delay (sec)	Total Stops (veh/h)	Stop Rate	Longest Que per Lane (vehs)	(m)	Perf. Index	Aver. Speed (km/h)	Fuel Rate (ml/km)
10 T	139.23	141.3	6031	1.70	55.8	335	455.22	17.9	148.7
11 T	2.91	53.8	169	.86	1.6	9	13.35	31.6	110.0
12 T	83.27	165.2	3223	1.78	29.8	179	250.79	16.0	157.3
13 T	22.14	164.0	852	1.75	7.9	47	66.51	16.1	156.4

Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Total Delay (veh-h/h)	Aver. Delay (sec)	Total Stops (veh/h)	Stop Rate	Perf. Index	Aver. Speed (km/h)	FUEL Rate (ml/km)	FUEL Total (ml/h)
6042	247.56	147.5	10274	1.70	785.87	17.3	150.6	910042.9

1

Table S.7 - LANE PERFORMANCE

Mov No.	Lane No.	Effective Red and Green Times (sec) R1	G1	R2	G2	Arv Flow (veh/h)	Cap (veh/h)	Deg. Satn x	Aver. Delay (sec)	Stop Rate	Back of Queue (vehs)	Back of Queue (m)	Short Lane (m)
10	1 T	60	60	0	0	887	850	1.043	141.3	1.70	55.8	335	
	2 T	60	60	0	0	887	850	1.043	141.3	1.70	55.8	335	
	3 T	60	60	0	0	887	850	1.043	141.3	1.70	55.8	335	
	4 T	60	60	0	0	887	850	1.043	141.3	1.70	55.8	335	
11	1 T	112	8	0	0	49	113	.430	53.8	.86	1.6	9	
	2 T	112	8	0	0	49	113	.430	53.8	.86	1.6	9	
	3 T	112	8	0	0	49	113	.430	53.8	.86	1.6	9	
	4 T	112	8	0	0	49	113	.430	53.8	.86	1.6	9	

Table S.15 - CAPACITY AND LEVEL OF SERVICE (HCM METHOD)

Mov No.	Mov Typ	Green Time Ratio (g/C) 1st grn	2nd grn	Total Flow (veh/h)	Total Cap. (veh/h)	Deg. of Satn (v/c)	Prog. Factor	Aver. Delay (sec)	LOS
10	T	.500*		3547	3400	1.043*	1.00	141.3	F
11	T	.067*		195	453	.430	1.00	53.8	E
12	T	.258*		1814	1757	1.033	1.00	165.2	F
13	T	.075*		486	510	.953	1.00	164.0	F
Intersection:				6042	6120	1.043		147.5	F

Level of Service calculations are based on overall delay.

* Maximum v/c ratio, or critical green periods

- **Summary of Intersection Performance with best Alternate**

Table S.3 - INTERSECTION PARAMETERS

Crit Mov No.	Green Period	Phases Fr	Phases To	Adjusted Lost Time, l	Adjusted Flow Ratio	Required Grn Time Ratio	Required Movement Time
10 T		1	2	7	.484	.538	41.9
13 T		2	1	7	.135	.150	16.7
		Total:		14	.618	.687	58.7

Cycle Time:

Minimum	Maximum	Practical	Chosen
28	120	45	65

Cycle Time = 65

Table S.15 - CAPACITY AND LEVEL OF SERVICE (HCM METHOD)

Mov No.	Mov Typ	Green Time Ratio (g/C) 1st grn	Green Time Ratio (g/C) 2nd grn	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Prog. Factor	Aver. Delay (sec)	LOS
10 T		.615*		3145	4000	.786	1.00	11.5	B
11 T		.169		351	812	.432	1.00	24.2	C
12 T		.615		565	2954	.191	1.00	5.4	A
13 T		.169*		875	1100	.795*	1.00	36.8	D
		Intersection:		4936	8866	.795		16.2	B

Level of Service calculations are based on overall delay.

* Maximum v/c ratio, or critical green periods