Improvement of traffic performance at intersections in Karbala city

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Abstract. This study deals with the evaluation of traffic performance at the road network around the old city of Karbala from the southern side, at Al-Tarbia Street and Fatima Al-Zahraa Street, through the evaluation of intersections' performance. This is followed by suggestions of some improvement proposals, which vary from changing timing plan, geometric improvement, to change intersection type completely.

The study area composed of seven intersections, three intersections are four legs signalized, and the other four are roundabouts. The video recording technique is used to collect the traffic data for 27 approaches. These data are abstracted from video films using EVENT program, and processed by prepared EXCEL sheets. While, the spot speed data for each entire link in the network are collected using pavement marking method.

SYNCHRO software was used for evaluation and analysis of signalized intersections, suggestion of best timing plan, and coordination. SIDRA INTERSECTION software was used for evaluation and analysis of both signalized intersections and roundabouts. The best proposal was also evaluated for the target year.

1 Holy Karbala city

Karbala is one of the special cities in the Islamic world. It is famous due to its religious aspect. The old city, or city center, is holding the holy shrines of Imam Hussain (the grandson of the Holy Prophet of Islam) and his stepbrother Abbas. It lies between (41°, 10') to (44°, 20') longitude and (32°) to (31°) latitude, departed at about 110 km south-west away from Baghdad. It is surrounded by Al-Anbar city from the north and west, Al-Najaf city from the south, and Al-Hilla (Babylon) city from the east [1].

Karbala province's population increased to (852963) in 2007. Around 53% of them are living in Karbala city. The car ownership also increased by about 133% from 2002 to 2007 [2].

The Holy shrine, as located in the Central Business District area (CBD) represents the core area of the city. It is surrounded from the north and the western north by farms and groves of palm trees, and western desert from the south side. Therefore, the growth of the city extended towards the south side due to the availability of vacant land [3].

1.1 The city problem

The rapid growth of the city with the increased number of pilgrims as well as population and auto vehicles together with road network expansion, led to many traffic problems and intolerable congestion. Although the local governorate authorities implemented some roadway resurfacing and

traffic improvements. it does not solve most of the traffic congestion problems, especially at Central Business District (CBD) area.

The new growth in Karbala traffic congestion has been recognized as a serious problem in the city, which affects the economy, travel time, driver behavior and causes discomfort to drivers and visitors. The number of vehicles in Karbala increases rapidly without a considerable increase in the capacity of the road network, which leads to increase in delay times and lowers the level of service (LOS).

The study area as shown in Figure (1) represents the nearest road network (from the south side) to the old city, so it is strongly affected by pilgrims that the city attracts. Karbala city attracts around 15 million pilgrims per year during four major occasions and on Thursday night's (weekend). Traffic congestion in this area was increased with increasing traffic demand due to the presence of many activity centers such as schools, governmental buildings, shopping centers, and religious places.

These traffic conditions need to be studied and evaluated using modern software. This is to set the required traffic and geometric proposals to attain efficient traffic flow.

2 Study objectives

The main objectives of this study are to evaluate the traffic performance in the studied area, and suggest the required traffic and/or geometric solutions to alleviate the congestion problem at the selected network.

3 Data collection and abstraction

To achieve the study objectives, it is necessary to follow a designed procedure as in Figure (2) to gather the required data.

Fig. 1. The Road Network at Karbala City

Fig.2. Traffic and Geometric Survey Program

3.1 Geometric data

Geometric data have been collected by using GIS tools in map measurements depending on the available satellite photographs with an accuracy of 0.6m, updated to 2007 and available at Karbala municipality, like intersection spacing, right of way. Field measurements are conducted for additional data like geometric characteristics of approaches, number of lanes per approach at each intersection, lane width, and splitter island width for each intersection. In addition, some of the geometric features for roundabouts like entry and exit radius, island diameter, circulating width, and so on are drawn to scale and measured, and other features that cannot be measured in the field are also obtained, such as entry angle and effective flare length. Field survey is used to obtain the geometric features that cannot be drawn from satellite image due to unavailability of the updated one. The main geometric features of the selected intersections are shown in Table (1).

Table 1. Geometric Features for The Selected Intersections

Nodes	Approach	Entry Width (We)	No. of Entry lanes (ne)	Exit Width	Entry Radius (Re)	Entry Angle	Effective Flare Length (l)	Circulating Width (Wc)	No. of Circulating Lanes (nc)	Splitter Island Width	Inscribed Circle Diameter (ICD)	Central Island Diameter (ID)
		(m)	No.	(m)	(m)	(°)	(m)	(m)	No.	(m)	(m)	(m)
1*	E/W	14	4/3	10.5	17	---	---	---	---	3	---	---
	N/S	12.3	3/3	14	10	---	---	---	---	3.5	---	---
2**	E/W	18.6	4/4	22.6	28.8	36	18	20	4	8.3	67	27
	N/S	12.9	2/0	11.7	20.3	36	9	20	4	5.3	67	27
3**	E/W	18.6	4/4	23	28.8	36	18	20	4	8.3	67	27
	N/S	12.9	2/3	11.7	20.3	36	9	20	4	5.3	67	27
4**	E/W	16.1	4/4	17.9	50	56	17.4	17	4	5.8	102	68
	N/S	16.1	3/3	18.4	55	56	18.2	17	4	5.3	102	68
5*	E/W	9	3/3	12.3	14.5	---	---	---	---	12.9	---	---
	N/S	12.5	3/3	15.5	58.5	---	---	---	---	17	---	---
6**	E/W	11	2/2	10	30	30	0	16	2	11.7	53	21
	N/S	8.8	2/2	14.5	36	30	0	16	2	11	53	21
7*	E/W	12.5	4/3	12.8	24.5	---	---	---	---	7.9	---	---
	N/S	11	3/3	12.8	16	---	---	---	---	4.8	---	---

* Signalized Intersection

** Roundabouts

3.2 Traffic data

The traffic flow data are recorded by using a video camera. Data are recorded on 8mm video camera tapes and later copied onto solid disk. The study area is characterized by a morning peak period of (7:00-9:00 A.M.) and evening peak period of (5:00-7:00 P.M.) for typical weekdays (Monday, Tuesday, and Wednesday) and Thursday.

The abstraction process of the required data is carried out with the aid of EVENT software, which turns the computer into a data capturing device and provides a digital representation of the observed data. Data abstraction was based on sessions of 15 minute periods of recorded data.

After data abstraction stage, data processing is made with the aid of a spreadsheet program. Excel program is used in abstracting data files, obtained from EVENT program. These programs are used to measure the main traffic parameters that are illustrated in Table (2).

Table 2. A Summary of Abstracted Data

Major Category	Data Type
Traffic volume data	<ul style="list-style-type: none"> Through and turning traffic volume counts Vehicle classification
Driver performance characteristics data	<ul style="list-style-type: none"> Headways and saturation flow rate
Signal timing control	<ul style="list-style-type: none"> Cycle length Phase sequence

The output files from EVENT program are opened with the aid of EXCEL program. This program has an option which converts text data to columns. This method separates the recording time into a column and the associated character in the next column. This arrangement makes the dealing with the data easier by sorting them into digits and characters.

For traffic volume data calculation, Pivot table was used to calculate the number of each character presented in the selected column. Other time-related parameters (saturation headway, phase and cycle length) were calculated by arranging EVENT output file in a set of columns according to their characters. Then, subtracting of one digit from another to find the value (time) for the subjected parameters. The traffic data that have been collected are as follows:

3.2.1 Traffic Volume Data

This data includes counting the traffic volumes abstracted from video recording for each approach at the intersections in the selected network, also, traffic composition, and the volume of turning movements. The network average traffic volume (veh/hr) is shown in Figure (3) for typical weekdays.

Fig.3. Hourly Traffic Volume for Average Typical Weekdays

Roundabouts turning movement estimates were derived from collected traffic volume data as recommended by the Federal Highway Administration [4]. The FHWA procedure requires the entering, exiting, circulating, and right turns for each leg of the traffic circle, as in Figure (4). Traffic passing ‘through’ the roundabout and ‘left turning’ vehicles were determined from Equations (1), and (2), respectively, and the definition of each term is shown graphically in Figure (4) [4,5].

$$V_{EB, through} = V_{EB, entry} + V_{WB, Exit} - V_{EB, right} - V_{NB, right} - V_{NB, circ.} \quad (1)$$

$$V_{EB, left} = V_{EB, entry} - V_{EB, through} - V_{EB, right} \quad (2)$$

where:

$V_{EB, through}$: traffic volume at the east-bound (West) approach, moving to through direction.

$V_{EB, entry}$: traffic volume at the east-bound (West) approach, entering the roundabout.

$V_{WB, exit}$: traffic volume at the west-bound (East) approach, exiting the roundabout.

$V_{EB, right}$: traffic volume at the east-bound (West) approach, moving to the right direction.

$V_{NB, right}$: traffic volume at the north-bound (South) approach, moving to the right direction.

$V_{NB, circ.}$: traffic volume upstream to the north-bound (South) approach, moving in the circulatory roadway.

$V_{EB, left}$: traffic volume at the east-bound (West) approach, moving to left direction.

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Fig.4. Turning Movements per Approach

This numerical method (Algebraic Solution Procedure) was also checked with the method mentioned in [5]. This method named live recording of turning movement patterns using field observer. This is only feasible under low traffic volume conditions where the entire roundabout is visible from one location.

3.2.2 Forecasting Traffic Volume Data

The annual rate of traffic increase in Karbala City is estimated to be (5%) of growth as stated by the [2].

This value is used as an input value to SYNCHRO program in volume tab from network setting. The printout of this stage is illustrated in Figure (5) for forecasted traffic volume.

Fig. 5. Forecasted Traffic Volume to the Target Year Using SYNCHRO

3.2.3 Speed Data

These data include the measuring of travel times for each internal link within the selected network. The travel time can be converted to the speed as illustrated in Figure (6).

Fig.6. Average Spot Speed for Each Link in the Network

3.2.4 Traffic Signal Data

The traffic signals data include the measuring of existing cycle time length, phase length, start up lost time, extension of effective green, and phase sequence.

Cycle length and length of phases have been extracted from video films for the subjected intersections and shown in Table (3). While, the values of both lost time types and extension of effective green are taken as the default values recommended by SYNCHRO and SIDRA software programs, as given in Table (4).

Table 3. Phase Order and Cycle Length for Signalized Intersections

Intersection	Phase Length (sec)				Cycle Length (sec)
	↕	↔	↗	↘	
1	25	24	41	23	121
5	27	21	20	15	91
7	24	38	14	31	115

Table 4. Lost Time and Extension of Effective Green Time for the Selected Software

Software	Lost time	Extension of Effective Green Time
SYNCHRO	2.5 sec	2.5 sec
SIDRA	2.0 sec	2.0 sec

4 Evaluation of existing traffic flow

To investigate the existing conditions of traffic operation schemes and geometry on traffic flow performance, simulation of the actual movement is required. These have been done by applying two software programs as follows:

4.1 Application of SIDRA software program

The abstracted and collected data required for this software were fed into the program for each intersection alone. Many runs were implemented to exclude the bias data.

SIDRA INTERSECTION software was used to analyze the existing traffic flow patterns for intersections as isolated at the study area.

Table (5) indicates the output results of simulation runs which include the degree of saturation, total delay, and level of service for each intersection in the study area. All the output results are categorized by medium to high total delays. Thus, the level of service for most of the intersections is (F) according to the LOS categories of the software that based on HCM method.

It is worthwhile to mention that some geometric improvements have been recently made to Al-Tarbia Street. The capacity of this street increased and the level of service (LOS) of the intersections (2&3) are (A and B). But, intersections (1&4) at the beginning and end of this street still suffer from high congestion and low traffic performance characterized by high delay values.

Table 5. Total Delay and Level of Service for the Existing Traffic Flow for Isolated Intersections Produced by SIDRA

Intersection	Max. Degree of Saturation (v/c)	Average Delay (sec / veh)	LOS
1*	1.89	253.6	F
2**	0.75	9.4	A
3**	0.56	10.1	B
4**	2.80	284.8	F
5*	1.31	97	F
6**	1.57	140.5	F
7*	1.13	76.9	E

* Signalized Intersections

** Roundabout

4.2 Application of SYNCHRO/Sim traffic software

SYNCHRO/SimTraffic was also applied to simulate the existing traffic flow for all the intersections at the selected network.

Although, SYNCHRO program v.6 is the first version which can analyze multi-lane roundabout, but, it is based on HCM method for roundabout analysis, so only the degree of saturation (v/c) can be obtained from this program, while, SimTraffic have the ability to simulate and analyze both the signalized and unsignalized (roundabout) intersections.

SYNCHRO and SimTraffic have similar delay results for (v/c) less than 0.85, as v/c increases, different results are obtained for the delay. This software has been applied for the selected intersections and the analysis results are presented in Table (6).

Table 6. Total Delay and LOS for Isolated Intersections Produced by SYNCHRO/Simtraffic for Existing Condition

Intersection	SYNCHRO			SimTraffic
	Max. Degree of Saturation (v/c)	Average Delay(sec/veh)	LOS	Average Delay(sec/veh)
1*	2.08	294.3	F	160.7
2**	1.00	N/A	N/A	57.1
3**	2.75	N/A	N/A	224.8

4**	8.80	N/A	N/A	408.9
5*	1.29	109.8	F	67.5
6**	2.90	N/A	N/A	1450.2
7*	1.35	105.5	F	73.3

* Signalized Intersections

** Roundabout

The results in Table (6) show that most intersections suffer from an oversaturation condition with high total delay values. SYNCHRO gives unreasonable results for high traffic volume, and large dimension roundabout (intersection 4), While, simTraffic gives unreasonable results at roundabout (intersection 6).

5 Improvements

SYNCHRO has the ability to optimize and coordinate the network with signalized intersections. While, SIDRA enables the user to analyze, and evaluates roundabouts with different geometries, so, it will be used for roundabouts improvement.

At the improvement process, the degree of saturation (v/c) was used as an indicator for diagnosing the oversaturated cases. Intersections having v/c ratios equal or greater than 0.9 need to be improved at the first stage.

This section divides the improvement strategies into two parts according to method and software applied. The first part is for signalized intersections (1, 5, and 7). The improvement type is suggested and evaluated by SYNCHRO program. The second part is for all the oversaturated intersections in the studied area. The signalized intersections that cannot be solved by the first part and the roundabouts (4, 6) are involved in the second part. The improvement type is suggested by the researcher and evaluated by SYNCHRO program for signalized intersections, and SIDRA for roundabouts.

5.1 Signal timing optimization and coordination

Traffic signal timing optimization is one of the most cost-effective methods for reducing vehicle operating costs and improving traffic flow performance along urban arterials. Arterial signal optimization models are developed to assist traffic engineers in coordinating traffic signal settings along urban arterials and across networks [6].

SYNCHRO contains a number of optimization types. It optimizes cycle length, split times, offsets and phase sequence to minimize driver stops and delay times. These types are applied to the network in the same order shown in Figure (7) [6].

Fig. 7. Optimization Steps in SYNCHRO

The range of cycle length recommended by HCM is 60-120 seconds. Long cycle length exceeding 100 seconds will be recommended to accommodate an extra 10% capacity. Long cycle lengths more than 120 seconds may have negative operation aspects including long queues, inefficient use of turning lanes, and blocking. Low cycle lengths may be better to reduce queues which in general increase capacity and provide smoother traffic operation [7]. The optimization results with the HCM recommended cycle range do not result in optimum cycle length, so the default range of SYNCHRO was used.

To calculate the best cycle time and the optimal timing of the existing phase sequences of the observed intersections, SYNCHRO was used. The range of cycle times used in the optimization process was 50-200 seconds, as default values by SYNCHRO. This range was used for each observed isolated intersection. Table (7) provides a summary of the optimization results. This is together with the best cycle time for each intersection in the observed network.

This Table shows that the use of optimization functions for the isolated signalized intersections such as split and offset has a minimal effect on the MOE for intersections (1 and 7) and has no effect at the intersection (5).

The optimization results showed that although the cycle time increased to non-reasonable values, the isolated intersections remain performing under oversaturated conditions, so, it is necessary to improve the performance by coordination.

One of the most common methods for increasing the efficiency of traffic operation is coordination of traffic signals. This is because; the higher increase in the traffic demand will result in a higher increase in the need for coordination. Traffic signal coordination can reduce the traffic congestion in many areas. Substantial improvements in traffic flow and reduction in delay, fuel consumption and stops could be achieved by coordination.

After the coordination process for signalized intersections in the network, the delay times were reduced by 2.8 % and 33.6% for intersections (1) and (5) respectively, while, a reduction of 52.3% is attained at the intersection (7).

Although the optimization and coordination runs improve the network MOE. But, the degree of saturation does not been reduced to a value less than 0.9.

Table 7. Measure of Effectiveness for the Improved Intersections with the Optimum Cycle Length Produced by SYNCHRO

Intersection	Improvement Type	Cycle Length	Max v/c	Total Delay		Total Uniform Stop		Total Fuel Consumption		Un-served vehicles
		sec		veh hr/hr	sec/veh	veh-hr/hr	%	Li	km/L	No.
1	Base Condition	121	1.82	213	337	3937	0.69	1417	2.9	1368
	Split	121	1.78	215	341	3935	0.69	1427	2.9	1368
	Cycle length	150	1.7	207	328	3986	0.70	1390	3	1281
	Network cycle length*	150	1.7	207	328	3986	0.70	1390	3	1281
	Phasing Sequence	150	1.93	202	320	4131	0.72	1374	3	1171
	Percent Saving			2.8	2.7	-1.2	-1.4	1.9	-3.4	6.4
5	Base Condition	91	1.28	110	123	2860	0.71	724	4.7	520
	Split	91	1.28	110	123	2860	0.71	724	4.7	520
	Cycle length	138	1.11	74	82	3069	0.76	615	5.5	105
	Network cycle length*	112	0.97	73	82	3056	0.76	615	5.5	98
	Phasing Sequence*	73	0.75	16	14.5	2352	0.58	418	8.1	0
	Percent Saving			85.5	88.2	18.3	15.2	42.3	-72	100
7	Base Condition	115	1.43	153	181	3043	0.71	763	2.7	677
	Split	115	1.37	166	197	2988	0.70	8.5	2.5	520
	Cycle length	150	1.31	157	186	3134	0.73	778	2.6	657
	Network cycle length*	150	1.31	73	82	3065	0.76	615	5.5	98
	Phasing Sequence	150	1.16	208	246	3320	0.78	949	2.1	209
	Percent Saving			52.3	54.7	-0.7	-7.0	19.4	-103.7	85.5

* Best improvement type

The percent saving is measured for the best improvement type.

Another trial was made by changing the number of phases and the phasing sequence. The phasing order in Iraqi's four-leg intersection is four split phases for through and left traffic with permitted right turn and yields only for pedestrians. The leading and lagging and any other protected phase are not used in this system, so the driver is unfamiliar with such type of movement. It may cause problems with head-on collisions between oncoming left turns. Due to these reasons, it will not be applied in this study.

At the intersection (5), due to the presence of overpass for through traffic at the east-west approach, changing the phase sequence with the lead/lag option is applied. The result shows 85% delay saving and 100% vehicles in the intersections are served.

5.2 Geometric Improvement

Since the coordination process does not satisfy the aforementioned objectives, so it is necessary to improve the geometries of the oversaturated approaches at intersections (1, 4, 6, and 7).

The improvement strategies will be as follows:

1. Re-marking of pavement.
2. Pavement widening.
3. Change the intersection type.

The MOE produced for each strategy is illustrated in Table (8) for signalized intersections analyzed by SYNCHRO, and Table (9) for roundabouts analyzed by SIDRA.

The first step of the geometric improvement is to apply pavement remarking. From the measurement, it can be noticed that the number of lanes in many approaches of these intersections can be increased by decreasing the lane width (with keeping the width of lanes greater than a minimum value of 2.4 m) according to HCM which is actually observed to be used in the field.

Increasing the number of lanes will increase the saturation capacity of the affected approaches, which leads to improving traffic performance MOE for some intersections at the selected network. Therefore, in this step consideration was given to remark the approaching lanes so that rearranging of queuing vehicles at stop line is obtained.

Also, separating the movement with high traffic volume by exclusive lane is also applied. Optimization run after each improvement type is applied for the signalized intersections; results are shown in Table (8).

Even the pavement remarking is applied to each approach of Al-Hakeem Intersection (intersection 1). This method improves the MOE but not to the desired level.

A suggestion of prohibition of U-turning vehicles at the intersection area by providing U-turn opening upstream for all approaches is applied. This reduces the best cycle time to 100 seconds, and reduces all the measure of effectiveness but not to the desired level.

Another trial was made by widening the east approach due to the presence of wide sidewalk at this section taking into consideration pedestrian volume. Also, shifting of the central island to meet the design criteria is applied at this approach as shown in Figure (8). The obtained results do not reduce the v/c to value less than 0.9. This supports the suggestion of Updated Karbala Master Plan [1] to adopt an overpass at north-south direction. This will reduce v/c to 0.83.

The delay times at the west approach does not reach the desired level, especially for left turning movement at the mentioned intersection, so another suggestion is made by changing the intersection type to a roundabout. Since roundabouts serve left turning movement. Results obtained by SIDRA and illustrated in Table (8) show an increase in all MOE and reduce v/c to a maximum value of 0.66 for the north approach.

The traffic problem at Al-Sayed Jawda Intersection (intersection 7) is solved by dividing the approach width into four lanes; each lane has its exclusive movement.

The traffic lanes that have low traffic volume are assigned to be shared. After the optimization process is applied, the optimum cycle length is set to be 104 sec and v/c is 0.87. So the intersection is in under-saturated condition.

Changing the four-leg signalized intersection to roundabout intersection with circulatory width equals to 14m and island diameter of 30m reduce v/c drastically to 0.47, and the average delay to 7 secs, as seen in Table (8). Figure (9) shows the intersection before and after geometric improvement.

Table 8. Measure of Effectiveness for the Improved Intersections with the Optimum Cycle Length Produced by SYNCHRO

Intersection	Improvement Type	Cycle Length	Max v/c	Total Delay		Total Uniform St		Total Fuel Consumption		Un-served vehicles
		sec		veh hr/hr	sec/veh	Veh-hr/hr	%	Li	Km/L	
1	Base Condition	121	1.82	213	337	3937	0.69	1417	2.9	1368
	Pavement marking	124	1.09	78	124	4084	0.72	830	5	276
	Prohibition of U-turn	100	1.04	51	74	3528	0.68	644	5.9	44
	Pavement Widening	104	0.98	41	59	3592	0.69	603	6.3	0
	Overpass	102	0.83	26	27	1948	0.51	354	7	0
	Roundabout*	---	0.66	12	11	3779	---	265	---	---
	Percent Saving			94.4	96.7	4.01	26.1	81.3	-141	100
7	Base Condition	115	1.43	153	181	3043	0.71	763	2.7	677
	Pavement Remarking	104	0.87	40	47	3251	0.76	379	5.1	0
	Roundabout*	---	0.47	9	7	3677	---	267	---	---
	Percent Saving			73.9	74.0	-6.8	-7.0	50.3	-88.9	100

* Analyzed by SIDRA program

Fig. 8. Improvement Proposal for Al-Hakeem Intersection

Fig.9. Improvement Proposal for Al-Sayed Jawda Intersection

Al-Zahraa square (intersection4) suffers from a high degree of congestion, especially from the East approach. Remarketing of the pavement alleviate the P.I by about 75%, but it is still under the oversaturated condition, and needs further modification to achieve the objected delay and performance index.

Since the width of circulating roadway has a great effect on capacity, thereby delay [8]. The circulatory width is suggested to be increased by trimming the central island diameter by 8m. In addition to the adjusting splitter islands shape to provide an extra pavement area for entering and exit approaches, as shown in Figure (10). The results in Table (9) show the degree of saturation is still over the desired limit.

Installing metering signal at West approach controlled by the demand for East approach is proposed. This is to create gaps in the circulating flow that assists the controlling approach traffic (East approach) to enter the roundabout.

The use of metering signals is a cost-effective measure to avoid the need for a fully-signalized intersection treatment [9,10,11,5]. Roundabout metering signals are installed on selected roundabout approaches and used on a part time basis since they are required only when heavy demand conditions occur, during peak periods [10,11].

Fig.10. Improvement Proposal for Al-Zahraa Square

The use of metering signal can provide beneficial operational benefits during these peak periods. In some cases, metering may be a more cost-effective solution as compared to the geometric improvements, particularly if the traffic condition requiring metering is of a short duration. A basic metering system consists of two components [5]:

A queue detector, located on the downstream entry, is experiencing excessive delays and queues. The queue detector should be placed relatively far back on the downstream entry to detect when there is a long queue. When a long queue is detected, the signal controller activates the metering signal.

A metering signal on the dominant approach, preferably set far back enough from the entry to minimize misunderstanding with the yield sign. If the metering signal cannot be set back adequately, some countries (e.g., Australia) use a special changeable message sign that exhibits a yield sign but can be changed to read "Stop on Red Signal".

Table 9. MOE for the Improved Intersections Produced by SIDRA

Intersection	Improvement Type	Max v/c	Total Delay		Total Uniform Stop veh/hr	Total Fuel Consumption Li/hr	Performance Index P.I
			veh – hr/hr	sec/veh			
4	Base Condition	2.8	801	485	34774	1970	1482
	Pavement Re-marking	1.57	159	77.3	10974	727	456.4
	Widening Wc	1.39	144	69.6	16370	701	475.7
	Widening We	1.13	98	59.8	14356	687	456.7
	Metering Signal	0.99	50	24.3	11602	556.1	325.9
	Percent Saving		93.7	94.9	66.6	71.7	78.0
6	Base Condition	1.57	228	140.5	20621	722	591.2
	Pavement Re-marking	1.78	155.5	95.8	13214	575.9	404.6
	Widening We	1.03	41.7	25.7	8640	406.3	216.5
	Widening Wc	1.03	40.9	25.2	8550	404.9	214.3
	Curb-shifting	0.89	24.0	14.8	7161	374.9	174.2
	Percent Saving		89.5	89.5	65.3	48.1	70.5

Pavement remarking at Al-Safeena intersection (intersection6) results in lower delay times, stops, and P.I. this with an increased value of v/c. So the widening of the South approach is necessary to add an extra lane. For the North approach, adding 2.5 m to the circulating width to be 12m was applied, as shown in Figure (11).

The entry radius for the East, South, and West approaches are increased. The increase in entry radius is recommended to increase flare length, and entry width and consequently increase the approach capacity.

Fig.11. Improvement Proposal for Al-Safeena Intersection

6 Forecasted network

The growth factor (i.e. traffic forecast factor TFF) was introduced for the application of forecasting traffic volume on the improvement proposals, for the signalized intersection. The growth rate together with the analysis period is applied with SIDRA for the application of forecasting traffic volume on the improvement proposals, for roundabouts (2, 3, 6, and 7), and roundabouts with metering signals (4).

Table (10) shows the MOE obtained from SYNCHRO and SIDRA optimization runs after the best improvement strategy for the target year.

Table 10. MOE Produced by SYNCHRO & SIDRA after Best Improvement Strategy for the Base Year, and Target Year

Intersection	Base Year		Target Year	
	Average Delay (sec/veh)	LOS	Average Delay (sec/veh)	LOS
1**	11.0	B	18.6	B
2**	9.4	A	13	B
3**	10.1	B	18.4	B
4***	24.3	C	80	F
5*	14.5	B	25.9	C
6**	14.8	B	36.4	D
7**	7.3	A	14.2	B

* signalized intersection

** Roundabout

*** Roundabout with metering signals at peak periods

This Table indicates that five of the intersections will perform well till five years later, except Al-Zahraa square (intersection 4). Opening the North approach for traffic at the intersection (3) may reduce the right turning vehicles of the East approach by 50%. This may reduce the future delay. Also installing the metering signal at the West approach, and leading the controlling approach in the South approach instead of the East. This will reduce the average future delay time to 29.6, and LOS C.

7 Conclusions

The main conclusion that can be drawn from this research is summarized as follows:

- 1) The optimization and coordination process slightly improve the selected network. This may be attributed to the presence of roundabouts between the signalized intersections that may disturb the platoon movements.
- 2) Pavement remarking and lane designation improves the intersections performance by an average of 50%.
- 3) Pavement widening, in addition to pavement marking, improve MOE of the intersections by an average of 66%.
- 4) Converting of closely spaced intersections to roundabouts, as in intersections (1, and 6), provides lower speed without stopping which is necessary to improve safety, especially in urban area. In addition to

the aesthetic view.

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