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Control and traffic signal warrant assessment of intersection sites

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Abstract Frequent evaluations are required to upgrade mobility and safety at intersections. This thus paper proposes a typical scenario to identify suitable controls for installing appropriate traffic signals.

   Five individual intersections were studied within the Babylon province, of Iraq, and graphical methods were used to identify suitable controls. Three graphs were adopted based on recommendations from the Institute of Highway Transportation (IHT), Department of Transportation (DoT) and the Iraqi Highway Design Manual (SORB). In addition, warrants for traffic signal installation according to the Manual Uniform Traffic Control Devices (MUTCD) regulations were checked with HCS 2010 software.

   According to IHT recommendations, three of the five intersections should be of a priority type and the others should take on a grade separation and a roundabout or a similar signal type. According to DoT, three of five intersections should be roundabouts and the rest Ghost Islands. The SORB recommends that all intersections should be controlled or altered to interchanges. Optimisation of suitable controls for each site should thus take all three methods into account in view of restrictions on area and budget. According to MUTCD, all of the intersections justify the installation of traffic signals, though further evaluation complementary to the proposed scenario would be useful.

1. Introduction

Intersections represent a critical part of any highway system, and their various characteristics determine the mobility and capacity of the entire system [1]. Thus, it is necessary to control and regulate traffic conflicts by applying convenient strategies to intersections. Such strategies rely mainly upon the crossing type and vehicular volumes, and determning suitable control types for traffic signal installation within intersections thus a considerable and very important issue.

   The main objective of the installation of control devices within any highway facility is to offer increased safety and mobility for both motorists and non-motorists. Control devices mostly involve signalisation and the provision of signs for warning and guidance [2]. In general, control of intersections takes three shapes: a priority shape ,which is a simple T-intersection, or one of the cross highways formats , either signalised or of a circular type, with a grade separation (interchange).

    Traffic signals are signalising devices positioned at highway intersections to control and regulate conflicting flows of highway users. They are one of the most limited forms of control devices that may be applied at crossings [3], though they provide a number of significant benefits such as increasing the capacity of the highway and reducing crashes [4]. However, unwarranted signals might cause additional problems such as excessive delay, signal violations, and traffic conflicts [5].

   The MUTCD [3] is currently widely used around the world to specify minimum traffic conditions (warrants) for the installation of traffic signals. These warants can thus be used as guidelines for

decision-making [6] by idetifying threshold conditions, based upon average or normal conditions, that, if found to be satisfied as part of an engineering study, warrant the addition of traffic signals.

2. Graphical methods of determining control types

Many local and international agencies have suggested procedures to determine suitable control types for a given intersection. One of these procedures is graphical methods, which depend only on the daily traffic volumes approaching the intersection.

The UK Institute of Highway Transportation (IHT) [7] suggested a layout for different levels of approaching volumes that consisted of three regions. A priority type region is either a simple three-legged intersection or a staggered intersection , crossroads , or similar form. The next type of region focuses on either signalisation or roundabout control, while the final one is concerned with interchange control.

Another layout is recommended by the US Department of Transportation (DoT) [8] ,and this comprisesd of four special regions. The simple control region is similar to that in IHT, while the additional Ghost island region is a simple intersection with channelisation . the single lane dual region focuses on the number of traffic lanes and roundabouts.

Similarly, the Iraqi Design Highway Manual (SORB) [9] suggests a particular layout that, as with the DoT layout, consists of four regions, in this case, an intersection without an island as region 1, channelization and divisional islands on minor intersecting highways for region 2, divisional islands on both major and minor intersecting highways for region 3, and interchanges for region 4.

3. Reasons for traffic signals

The MUTCD manual provides nine traffic signal warrants that address a variety of intersection conditions. Vehicular volume represents the central factor determining the installation of signal devices, and this has been included in the MUTCD since its first edition in 1935 [10]. Pedestrian requirements suggest the types of pedestrian crossing facility that should be provided under given traffic and site conditions [11], while student requirements are limited to school crossing zones. Crossings between highways and railroads also present a danger to vehicular traffic, and the installation of traffic controls at grade crossings decrease crashes and fatalities at highway/rail crossings [12].However, traffic signal controls should not be implemented if none of the warrants is met, despite these offering only an initial judgment. More traffic studies are often required to exercise a final engineering decision.

4. Study area

This study included five intersections situated in the northern part of Babylon province in Iraq, distributed mainly between Al-Musayib and Alexandria, as illustrated in Figure 1. The study area represents a strategic location that connects four provinces: Baghdad, Babylon, Al-Anbar, and Karbala. Alexandria city is home to more than 150,000 people [13], and it was selected for two sites with three-legged intersections, one of which is an unsignalised (The Station intersection), while the other is a signalised type (Al-Salam intersection) under the Baghdad-Babylon fly-over highway, as shown in Plate 1. Al-Musayib, has a population of about 124,000 [13], and three intersections there were selected .Two of these are unsignalised intersections: (Al-Irjoan intersection) with three legs and (Al-Sadah intersection) as a crossroad whereas the last is a signalised three-legged (Awlad-Muslim) intersection.
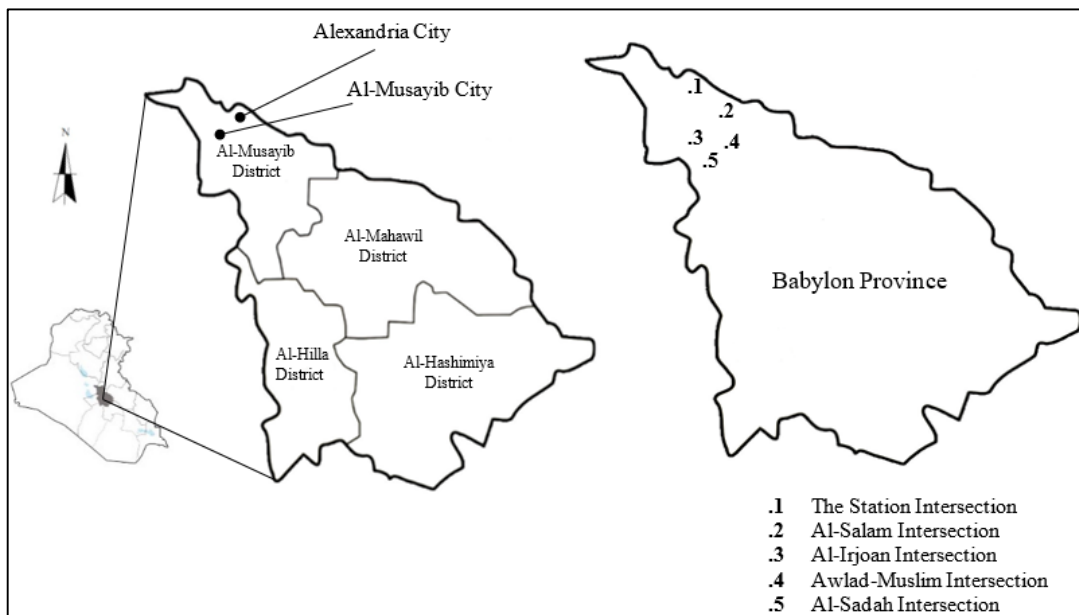
Figure 1. Map of the selected five intersections, Babylon, Iraq.

Plate 1. Al-Salam fly-over intersection, Alexandria, Iraq.

5. Data Collection
The study data were gathered in three ways.

5.1 Traffic data
Traffic data collection included identifying peak hours, pedestrian volumes, and number of students crossing a given portion of an intersection. Video techniques were utilised for collecting vehicular and pedestrian volumes within the study area in six-hour periods over two discrete weekdays per intersection. Two days was selected to provide an appropriate sample covering most ranges of traffic circumstances under standard conditions with no crashes or unusual occasions, and sunny weather conditions. The video technique is considered to be a reliable method for several reasons. The films can be reviewed at any time, reducing human mistakes error, and the cameras can be situated in high vantage points, making them not noticeable by highway users (see plate 2). Consequently, highway users are less likely to be distracted and the films produced will be more accurate and reliable.

Nevertheless, this technique still faces some challenges, most importantly security approval. Video recordings were continued in three periods during the specified weekdays: Morning (7:00 to 9:00), Noon (1:00 to 3:00) and Evening (5:00 to 7:00). Table 1 lists the extracted hourly volumes from the Al-Salam intersection.

Plate 2. Screenshot using the video technique at Al-Salam intersection ,October, 2018

Table 1. Sample of abstracted hourly volumes at Al -Salam intersection during the morning

		EB		NB			SB
Time		Left	Right	Left	Through	U-turn	Right
7:00	7:15	173	136	129	141	21	180
7:15	7:30	195	120	127	152	25	175
7:30	7:45	227	201	220	180	37	311
7:45	8:00	270	227	232	216	46	343
8:00	8:15	245	191	200	183	34	293
8:15	8:30	266	201	194	197	41	283
8:30	8:45	233	213	187	171	44	266
8:45	9:00	257	237	203	186	43	289

5.2 Geometric data
The geometric data included the number of traffic lanes and their median width. Geometric data were gathered using a mixture of several techniques. Initially, satellite images were used to obtain the required data such as corner radius, the angle of intersection and so on. The Android Tactical Assault Kit (ATAK) application, developed by the US Army, was used for this purpose [14]. Extra data was gathered from the respective local municipalities within the study area, and traditional manual methods characterised by the use of measuring tapes were also used in this study.

5.3 Additional data
The final data required included factors such as design speed, area population, and approximate number of students nearby. The populations of the surrounding areas were obtained from the Central Organization for Standardization and Quality in Iraq [13], while the highest number of crossing students during peak hours was obtained from the nearby schools.

6. Analysis and Results

   This section consists of two parts: The first part refers to the investigation of the proper type of controls for each intersection based on the daily approaching flow, while the second part is concerned with checking the MUTCD signal indicators.

6.1 Control type investigation
All hourly collected volumes for the five intersections were transformed to average daily traffic volumes. This transformation was done by using Hilla-Baghdad highway expansion factors [15], as listed in Table 2. The summation of daily traffic volumes for major and minor highways for each study intersection are plotted with the adopted three layouts.

Table 2. Daily P.C.U volumes for the five intersections (vehicle /day)

Intersection Name	Major highway	Minor highway
The Station	18450	2936
Al-Salam	25163	17235
Al-Irjoan	19913	3699
Awlad-Muslim	11261	2467
Al-Sadah	5336	4470

   There is a significant contrast in the results for type of control. For the IHT layout, all five points plotted represent average daily volumes for the five study intersections as in Figure 2. Three of five intersections are recommended as being of priority type (either simple T-junctions, staggered T-junctions or crossroads), one is recommended as a grade separation type and a roundabout or signal type is recommended for the final intersection.
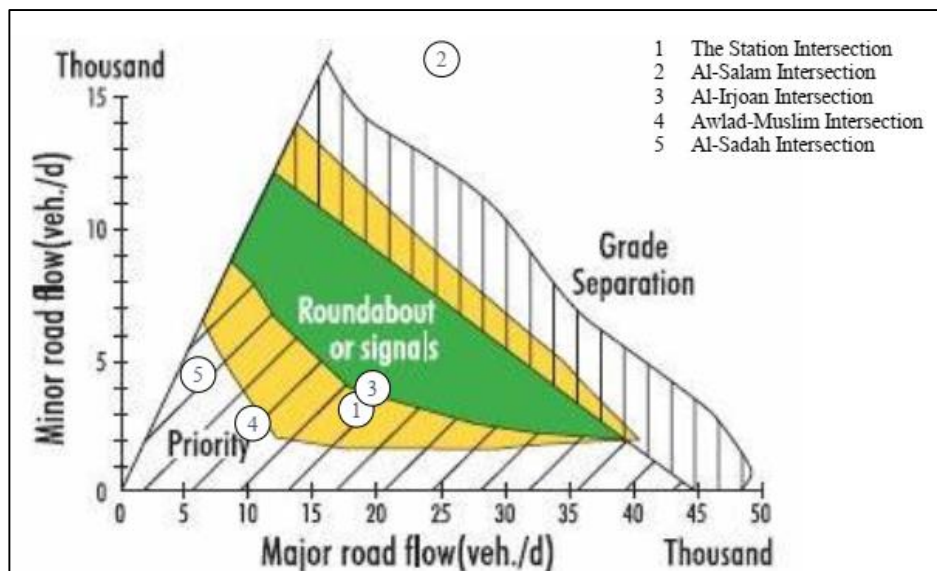

Figure 2. Study Intersections Control Types using IHT Graphical Method

   Figure 3 illustrates the DoT layout and the plotted points for the five intersections. Three of five intersections are suggested as a roundabouts and the rest are suggested as a ghost island controls. Similarly, the Iraqi Highway Design Manual recommends that all five intersections should be

controlled or altered to an interchange, as illustrated in Figure 4. It can be seen within that figure that all five points are beyond the borders. Table 3 summarises the results of the predictions for the appropriate type of controls for the five crossings from the presented graphs.
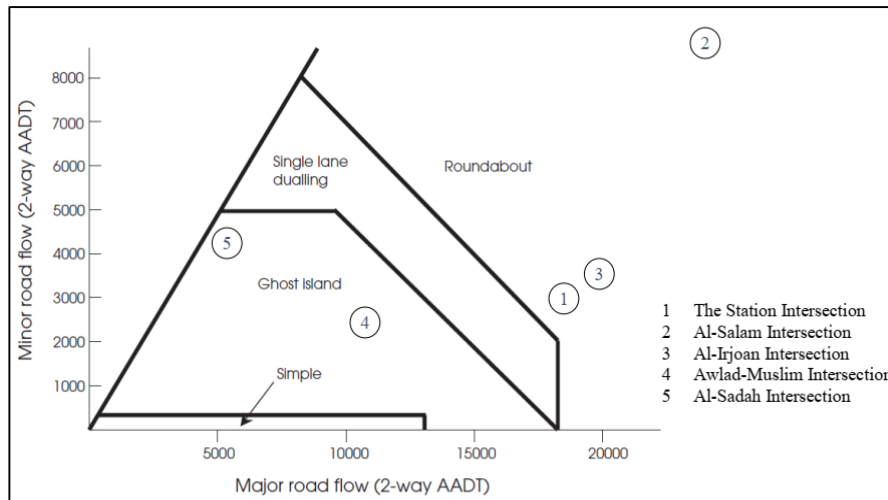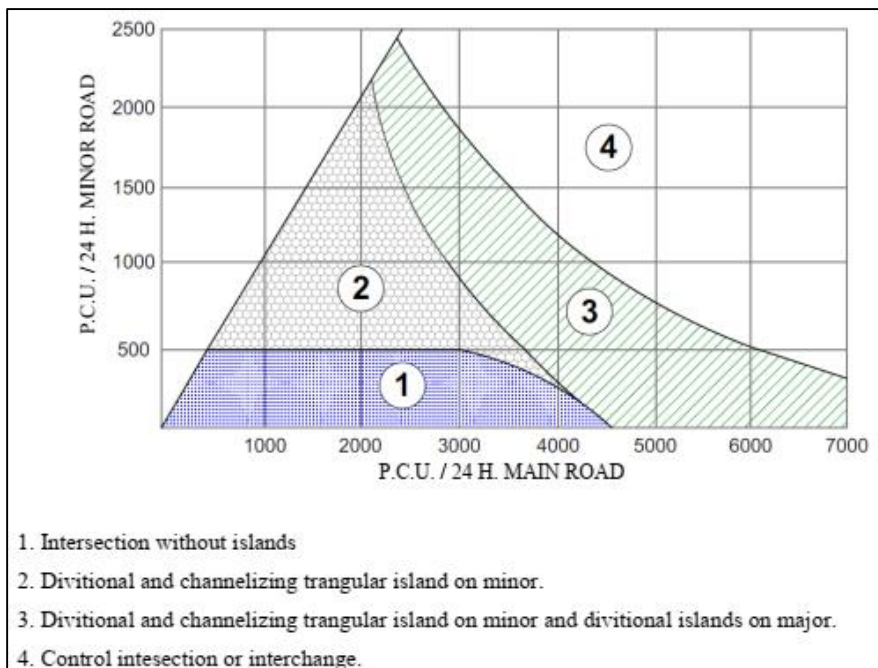

Figure 3. Study Intersections Control Types using DoT Graphical Method.

Note: All sites are beyond the excess of the Figure (control intersection or interchange)
Figure 4. Study Intersections Control Types using SORB Graphical Method.

Table 3. Results of control type selection for the five intersections

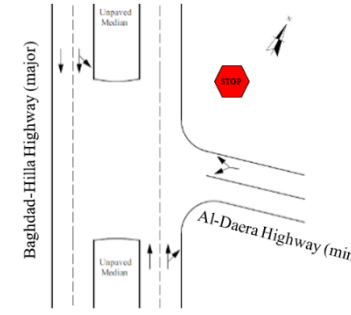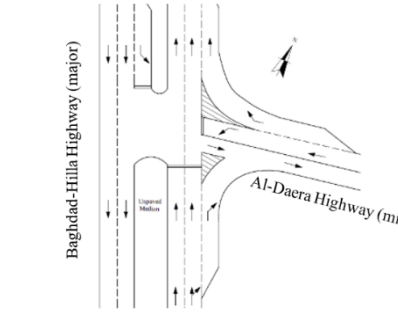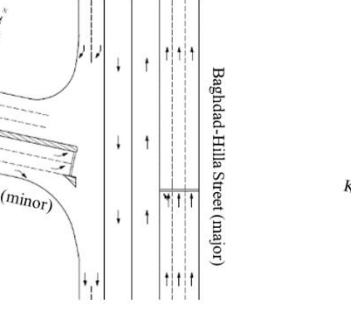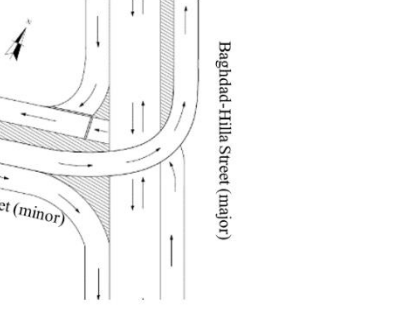| Intersection Name	Existing Condition	Proposal recommended		
		IHT	DoT	SORB
The Station	Priority	Priority	Roundabout	Control or Interchange
Al-Salam	Signal	Grade Separation	Roundabout	Control or Interchange
Al-Irjoan	Priority	Circular or Signal	Roundabout	Control or Interchange
Awlad-Muslim	Signal	Priority	Ghost island	Control or Interchange
Al-Sadah	Priority	Priority	Ghost island	Control or Interchange
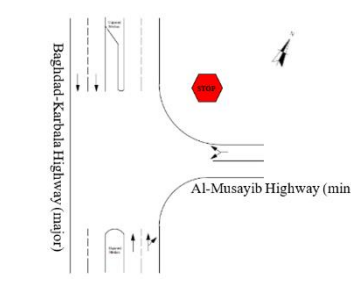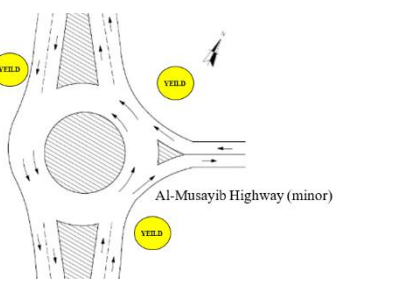
As listed in Table 3, there is a clear difference in the proposed results for the same intersections. Priority, roundabout, signalisation and ghost island (channelisation) types are thus applicable for short and mid-term evaluation. For long-term evaluation, an interchange thu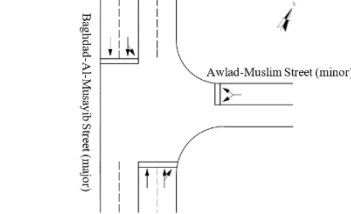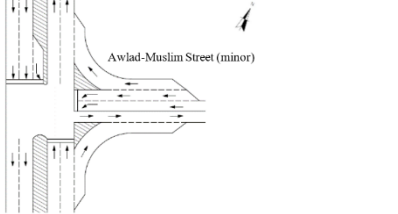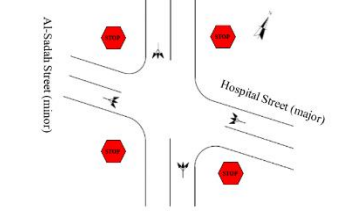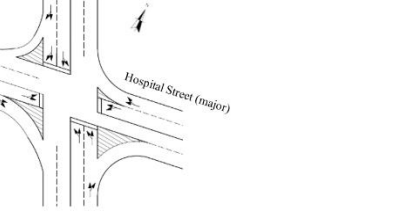s a proper alternative. A priority type provides little traffic safety and mobility, though it is an economical alternative and does not require much area acquisition. Although the the roundabout type of control is economic to some extent, it requires some area acquisition, and causes low travel speeds, though the high traffic capacity, safety, and mobility are desirable. Signalisation is also an economic alternative but may cause excess delays. Ghost Islands or channelisation offer poor safety and mobility, but offer an economic alternative. An interchange requires more area acquisition but offers high safety and mobility are very high; however, it is not economical compared with the short-to mid-term alternatives.

In terms of the short and mid-term evaluation, two of the five study intersections satisfy the recommendations, which are The Station and Al-Irjoan intersections. For the Al-Salam intersection, a roundabout is not applicable due to obstruction from the existing overpass columns and the area being surrounded by the Euphrates River and many governmental and commercial buildings. An interchange thus offers a suitable solution. For the Al-Irjoan intersection, a roundabout is a good choice since it reduces the number of conflict points as compared to signalisation.

The remaining intersections are not compatible with the recommendations, and a signal controls are more convenient for safety and mobility. For Awlad-Muslim and Al-Sadah intersections, neither priority nor ghost island channelisation is suitable, as these do not provide enough safety and mobility. Signalisation with channelisation is more convenient. For The Station intersection, a priority control offers poor safety, yet a roundabout is not preferable due to low operating speeds.

For long-term evaluation, interchange installation for all five intersections is the ideal proposal. Table 4 displays the existing and the recommended control types for the five studied intersections.

Table 4. Recommended control types for the five intersections

Intersection Name	Existing Condition	Recommended Control
The Station		
Al-Salam		
Al-Irjoan		
Awlad-Muslim		
Al-Sadah		

6.2 Signal warrant checking

The second part of this study tests the requirements for signalisation according to MUTCD guidelines. The related required data are formatted to allow easy comparison with the criteria, as listed in Table 5. A column of the traffic volume in each direction on the major street is included, and a column listing the (high volume) in one direction on a minor street is also included. Highway Capacity Software HCS 2010 was used to test the data against the warrants.

Table 5. Data for signal warrant testing for Al-Sadah intersection (vehicle/hour)

Time	Hospital Street (main street)			Al-Sadah Street (minor street)		
	EB	WB	Total	NB	SB	High
7:00-8:00 A.M	425	369	794 [a]	300	171	300 [b]
8:00-9:00 A.M	462	510	972	367	422	422
1:00-2:00 P.M	448	342	790	318	368	368
2:00-3:00 P.M	358	250	608	300	406	406
4:00-5:00 P.M	308	192	500	197	133	197
6:00-7:00 P.M	180	253	433	137	101	137

[a]   Total hourly volume from EB and WB approaches .

[b]   Highest hourly volume of the minor approaches.

The obtained hourly volumes for Al-Sadah intersection were plotted against the four-hour warrant graph (Warrant 2) .The centre decision curve (one lane Major Street with one-lane Minor Street) was used, and four of the six plotted hours of data were above the criterion; as at least four hours are required, the warrant is met.

The hourly volumes were plotted against the peak-hour volume warrant graph (Warrant 3). Again, the centre decision curve was used and four of the six hours of data were above the criterion, and the warrant is met.

Pedestrian volume (warrant 4) requires at least 190 ped/h crossing the major street for one hour or 100 ped/h crossing for four hours (not available). In the time, the number of acceptable gaps must be less than 60 per hour. The data indicated that there was one hour (8:00 to 9:00 AM) with more than 190 pedestrians (290) pedestrians crossing the major street and the number of acceptable gaps (35) was less than 60. Thus, the warrant is met.

For warrant 1 and warrants 5 through 8, no information was given, so these warrants cannot be applied.

Thus, signal installation should be considered at this location, as the criteria for Warrants 2, Warrants 3, and 4 are all met. A screenshot of HCS software report for Al-Sadah intersection is shown in Figure 5. Table 6 summarises the results of checking traffic signal warrants with HCS 2010 for all five intersections within the study area, making it obvious that all intersections examined should be signal controlled.

Warrants Summary											

Information											
Analyst	Moneeb			Intersection		Al-Sadah intersection					
Agency/Co				Jurisdiction							
Date Performed				Units		U.S. Metric					
Project ID				Time Period Analyzed							
East/West Street	Hospital Str.			North/South Street		Al-Sadah Str.					
File Name	al sadah			Major Street		East-West					

Project Description											

General						**Roadway Network**					
Major Street Speed (kph)	70	☐	Population < 10,000			Two Major Routes				☐	
Nearest Signal (m)	1000	☐	Coordinated Signal System			Weekend Count				☐	
Crashes (per year)	0	☐	Adequate Trials of Alternatives			5-yr Growth Factor				2	

Geometry and Traffic	EB			WB			NB			SB		
	LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Number of lanes, N	0	1	0	0	1	0	0	1	0	0	1	0
Lane usage		LTR			LTR			LTR			LTR	
Vehicle Volume Averages (vph)	32	132	16	48	82	28	44	47	42	23	67	42
Peds (ped/h) / Gaps (gaps/h)	--	/	--	--	/	--	--	/	--	--	/	--
Delay (s/veh) / (veh-hr)	--	/	--	--	/	--	--	/	--	--	/	--

Warrant 1: Eight-Hour Vehicular Volume	☐
1 A. Minimum Vehicular Volumes (Both major approaches --and-- higher minor approach) --or--	☐
1 B. Interruption of Continuous Traffic (Both major approaches --and-- higher minor approach) --or--	☐
1 80% Vehicular --and-- Interruption Volumes (Both major approaches --and-- higher minor approach)	☐
Warrant 2: Four-Hour Vehicular Volume	☑
2 A. Four-Hour Vehicular Volumes (Both major approaches --and-- higher minor approach)	☑
Warrant 3: Peak Hour	☑
3 A. Peak-Hour Conditions (Minor delay --and-- minor volume --and-- total volume) --or--	☐
3 B. Peak- Hour Vehicular Volumes (Both major approaches --and-- higher minor approach)	☑
Warrant 4: Pedestrian Volume	☑
4 A. Pedestrian Volumes (Four hours --or-- one hour) --and--	☑
4 B. Gaps Same Period (Four hours --or-- one hour)	☑
Warrant 5: School Crossing	☐
5. Student Volumes --and--	☐
5. Gaps Same Period	☐
Warrant 6: Coordinated Signal System	☐
6. Degree of Platooning (Predominant direction or both directions)	☐
Warrant 7: Crash Experience	☐
7 A. Adequate trials of alternatives, observance and enforcement failed --and--	☐
7 B. Reported crashes susceptible to correction by signal (12-month period) --and--	☐
7 C. 80% Volumes for Warrants 1A, 1B --or-- 4 are satisfied	☑
Warrant 8: Roadway Network	☐
8 A. Weekday Volume (Peak hour total --and-- projected warrants 1, 2 or 3) --or--	☐
8 B. Weekend Volume (Five hours total)	☐

Figure 5. Screenshot of HCS 2010 report for Al-Sadah intersection.

Table 6. Summary of the signal warrants analysis results

Intersection Name	Warrants			
	Four Hour	Peak Hour	Pedestrian	School
The Station	√ [a]	√	× [b]	×
Al-Salam	√	×	√	√
Al-Irjoan	√	√	×	×
Awlad-Muslim	√	√	√	√
Al-Sadah	√	√	√	×

[a]   indicates the warrant is met.

[b]   indicates the warrant is not met.

7. Conclusions and Recommendations

- Timely selection of the proper type of traffic control may have many economic impacts and save time with regard to evaluation studies on intersection sites.
- The various adopted graphs used to identify the proper type of control showed different results for similar intersections.
- Optimisation of suitable controls for each site within the three methods should be conducted in view of restriction of area and budget.
- Further evaluation for warrants of signal installation as complementary to the proposed scenario can help to fulfil any special local needs.
- Traffic signal installation is warranted for all five studied intersections.
- Traffic signal warrants may be considered a complementary part for any traffic study of intersection sites.
- More intensive traffic studies of traffic operation and geometric characteristics may be conducted for better mobility and safety.

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