Evaluation and Improvement of Three-Leg Intersections: A Case Study in Amman City

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ABSTRACT

Intersections are considered as the most critical elements of the urban roadway network. Although many studies concerned with evaluating and improving intersections in the urban area, so far few have concentrated on the unsignalized intersections, especially three-leg intersections. Therefore, the aim of this paper is to evaluate and improve four three-leg intersections controlled by the STOP sign in different locations in Amman City for the existing and short-term conditions. Highway Capacity Software (HCS-2010) and Synchro-10 software have been used for the evaluation and improvement. While VISSIM-11 software was used for validation and simulation. Evaluation processes using the HCS-2010 and Synchro-10 programs have shown that the left-turn from the minor-street faces high delay and operates in a breakdown traffic condition (Level of Service LOS-F). Warrant-3; (Peak Hour Volume) was applied to determine whether or not the selected intersections are warranted for signalization under existing conditions. The output results showed that three intersections are warranted for signalization and the fourth one is not satisfied. For short-term conditions with a growth of 5.5%, the results of the two-software revealed that the four selected intersections are warranted for traffic signals. The optimum cycle length of traffic signal was selected for each intersection, with two operation modes for the left-turn of the major-street; Protected and Protected-Permitted phase using HCS-2010 and Synchro-10 software and validated using VISSIM-11. The improvements in traffic and geometric conditions resulted in a reduction in vehicular delay with better LOS at the minor approach (LOS-C or LOS-D) as well as the entire selected intersections (LOS-B or LOS-C).

Keywords: VISSIM, Synchro, Three-Leg Intersection, Traffic Signal Warrants, Unsignalized Intersection.

1. Introduction

Transport system is a substantial and influential part of the infrastructure, which plays a stately role in a country's economic growth due to its significant importance in the transport of people and goods. One of the most important components of transportation system is the urban roadway network, where the signalized, unsignalized, interchange intersections and roundabouts are one of its components [1]. In Amman City, the capital of Hashemite Kingdom of Jordan, the urban roadway network faces many problems in traffic system. The recurring congestion and delay at intersections are the most critical issues requiring improvement in short, medium and long terms period of time.

According to the Yearly Report of Traffic Accidents in Jordan (2017), car ownership in Jordan grew from 1 vehicle per 58 persons in 1971 to 1 vehicle per 6 persons in 2017 [2]. This means an increase in demand and thus an increase in traffic volume that reflects adversely on the roadway network in terms of the Level of Service (LOS) provided by the facility to users. Congestion at intersections areas has a significant impact on the entire roadway network causing an increase in the number of stopped vehicles, delay, fuel consumption, and air pollution. However, improving any intersection will not only improve the operational performance of this intersection, but also improve the traffic conditions on the entire street in which this intersection is located [3].

As with signalized intersections, the main factor in the determining the LOS at the un-signalized intersections is the control delay. LOS at un-signalized intersections is defined only for minor-street movements and left-turn movement of the major-street approach but not for the other major-street movements as well as the entire intersection. This is because the major-street through movements are supposed to experience no delay, which may cover up the delay faced by minor approach movements and, consequently, misrepresents the overall delay and LOS for the entire intersection [1].

While many studies have focused on the evaluation and improvement of intersections within the urban area, so far few have focused on unsignalized intersections. Nicoli F., et al. have studied a corridor in Lucca, Tuscany, Italy. There were seven different intersections along the studied corridor including signalized, un-signalized (Two-Way Stop Control TWSC), and roundabouts. The present traffic situation at the corridor -which was analyzed by SIDRA-6.0- indicated that the LOS is (F). Several alternatives (such as replacing three consecutive intersections by a roundabout, elimination of left-turn by placing an island, staggered pedestrian crossing and parking areas) have been proposed resulting in LOS-D, which is considered a minimum value required in urban areas [4]. Meiping YUN and Jing JI compared the use of STOP or YIELD sign-control in terms of delay at an unsignalized intersection in China. Traffic performance was simulated and validated using VISSIM software. Depending on the least delay faced by critical traffic volumes, the decision to use traffic signs type (STOP or YIELD) can be made [5]. Ma dongfang, Song xianmin, Tao pengfei, and Wang dianhai presented a new model for warranting traffic signals in equal right-of-way traffic streams passing through unsignalized intersections based on traffic situations in China. By developing a critical volume curve based on the delay before and after signal control, the output curve can be used as a reference in installing traffic signals [6]. M. Dutta and M. A. Ahmed have analyzed and modeled the gap acceptance behavior in the minor-street approach of three T-intersection in India. They studied the relationship between the gap acceptance behavior and the gap duration. Accordingly, Two equations have been developed to estimate gap acceptance for aggressive and non-aggressive drivers in the study area [7].

2. Problem Definition

Four 3-legged isolated un-signalized intersections (STOP sign-controlled) in different locations in Amman City were chosen for this study. Personal field observation (using both participant and non-participant observation techniques) gave an indication that the minor-street movements as well as the left-turn of the major-street at these four intersections facing significant delay and long vehicles queue at peak hours. Therefore, it was clear that these intersections needed to be evaluated and improved over the existing-term (2019) and short-term (2024) periods of time in order to improve the operational performance and increase safety.

3. Study Area

The selected three-legged intersections as listed below:

3.1 First Intersection (Khalil Al-Saket Int.):

This intersection is located in the Al-Jubeiha District northwest of Amman City. The Northbound (NB) and Southbound (SB) approaches to the intersection are from Khalil Al-Saket Street (major-street), while the Westbound (WB) approach is from Sama Al-Serhan Street (minor-street) as shown in Fig. 1. The three approaches to the intersection have two lanes each with an undivided median.

Figure 1. Aerial Photograph for the First Intersection

3.2 Second Intersection (Um Uthaynah Int.):

This intersection connects two collector streets in the Um Uthaynah District in southwest of Amman City. The major street of the intersection is King Faisal Ben Abd Al-Aziz Street (NB and SB approaches), while the minor-street is Shatt Al-Arab Street (WB approach) as shown in Fig. 2. Each approach has two lanes with an undivided median.

Figure 2. Aerial Photograph for the Second Intersection

3.3 Third Intersection (Princess Sumayyah Int.):

This intersection connects two collector streets in Al-Sahel District in Amman City; Princess Sumayyah major-street (Eastbound (EB) and WB approaches) and Wahib Al-Afyouni minor-street (SB approach) as shown in Fig. 3. There is a raised curb median and two lanes at each approach to the intersection.

Figure 3. Aerial Photograph for the Third Intersection

3.4 Fourth Intersection (Al-Baraka Mall Int.):

This intersection connects two collector streets in Al-Swaifyeh District in Amman City; Saeed Al-Mufti major-street (EB and WB approaches) and Tarik Al-Jundi minor-street (SB approach) as shown in Fig. 4. There are two lanes at each approach with a raised curb median.

Figure 4. Aerial Photograph for the Fourth Intersection

4. Data Collection

For data collection purpose, a video recording technique was adopted in order to obtain the peak hourly volume for both major and minor approaches. The recorded videos were played several times to determine whether or not movement patterns (Left, Through, Right, and U-turn) are present at each selected intersection. Geometric conditions and any other data required for analysis and evaluation of the intersections were also collected as part of field survey. The peak hour factor (PHF) for each selected intersection was manually calculated. The PHF values varied from 0.87 to 0.94. Therefore, the default value of PHF=0.92 was adopted, as recommended by the Highway Capacity Manual HCM-2010 and HCM-sixth edition.

Based on direct field observations, the percentage of heavy vehicles (HV%) at the selected intersections ranged between 2% to 4%. Lane width varied from 3.0m to 3.6m depending on the different locations in the study area. The growth rate of 5.5% was used for short-term analysis and evaluation based on official contact with the Greater Amman Municipality (GAM).

Table 1 shows the Peak Hour Volume (PHV) passing through each approach of the studied intersections. The single approach column represents the minor approach traffic volume, whereas the merged approach columns represent the total traffic volume passing through both approaches of the major-street.

Table 1. Peak Hour Volume at Each Intersection

Intersection	Peak Hour Volume PHV (vph) EB	WB	NB	SB
1st Int.	-	231	1698	
2nd Int.	-	327	1379	
3rd Int.	1117		-	405
4th Int.	1135		-	245

5. Study Methodology

The evaluation of the operational performance of the selected unsignalized intersections in this study follows the procedure outlined in the HCM-2010 and HCM-sixth edition. Only left-turn movements from the major and minor streets as well as right-turn movement from the minor-street were evaluated. This is due to the assumption that the through-movements at the major-street are experiencing zero delay. Therefore, LOS is not measured for the entire intersection at unsignalized intersections [1].

The methodology of this study begins by evaluating the four intersections in the existing term (year, 2019) to determine delay and other Measures of Effectiveness (MOEs). The evaluation process is conducted using Synchro-10 and Highway Capacity Software (HCS-2010) computer programs and validated by the VISSIM-11 simulation tool. To prioritize the conflicting traffic movements at the four intersections, it was suggested that traffic signals be installed in accordance with the Peak Hour Volume warrant which is one of nine warrants that recommended by the Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD has listed nine warrants for signalization which, if any satisfied, the installation of traffic signal is satisfied. This satisfaction, however, is not mandatory for traffic engineers to install traffic signals. Field observing and studying whether or not the signalization will provide better operational performance and more safety benefits should be conducted [3], [8].

The justifications for the signalization at the four intersections was caried out using the Synchro Traffic Signal Warrant-10. The installation of traffic signals, if warranted, needs to choose an optimum cycle length, phase durations, and a left-turn mode to accommodate the traffic volume passing through the intersection in both the existing term (year, 2019) and short-term (year 2024 with a growth factor of 5.5%). Accordingly, two left-turn operation modes were selected and evaluated; Protected and Protected-Permitted.

Finally, several cycles from 60 to140 seconds were performed and evaluated for each intersection and left-turn operation mode; Protected and Protected-Permitted to select the optimum cycle length with the least delay, fuel consumption, air pollution and the best LOS.

6. The Evaluation

6.1 First Intersection:

The operational performance of the traffic and geometric characteristics of the intersection has been analyzed and evaluated using the HCS-2010 and Synchro-10 Programs and the results are summarized in Table 2.

The results of HCS-2010 Program showed that the minor-street left-turn has a delay of 275.6 sec/veh with LOS-F and an oversaturated flow (v/c) with 1.35. Whereas the results of Synchro-10 revealed that the delay in the left-turn of the minor-street is 278.7 sec/veh with LOS-F and v/c of 1.36. The analysis results also showed that the minor approach experiences high an overall delay of 171.3 sec/veh at LOS-F and 172.8 sec/veh at LOS-F in HCS-2010 and Synchro-10 programs, respectively.

Table 2. Evaluation Results of the First Intersection

		HCS-2010	Synchro-10

Approach	Major LT	Minor LT	Minor RT	Major LT	Minor LT	Minor RT
	SBL	WBL	WBR	SBL	WBL	WBR
Delay (sec/veh)	10.3	275.6	12.1	3.3	278.7	12.9
LOS	B	F	B	A	F	B
v/c Ratio	0.11	1.35	0.16	0.11	1.36	0.18
95%ile Queue (veh)	0.35	10.35	0.58	0.40	11.50	0.70
Approach Delay (sec/veh)	-	171.3		-	172.8	
Approach LOS	-	F		-	F	

6.2 Second Intersection:
The operational performance of the traffic and geometric characteristics has been analyzed and evaluated using the HCS-2010 and Synchro-10 programs. The results of HCS-2010 program revealed that the left-turn from the minor-street has a delay of 297.2 sec/veh with LOS-F and an oversaturated flow (v/c) with 1.40. The results of Synchro-10 revealed that the delay experienced by the left-turn from the minor-street is 291.0 sec/veh with LOS-F and v/c ratio of 1.39. The analysis results also exposed that the minor approach experiences high delay of 136.1 sec/veh with LOS-F and 133.8 sec/veh with LOS-F using HCS-2010 and Synchro-10 programs respectively, as shown in Table 3.

Table 3. Evaluation Results of the Second Intersection

	HCS-2010			Synchro-10		
Approach	Major LT	Minor LT	Minor RT	Major LT	Minor LT	Minor RT
	SBL	WBL	WBR	SBL	WBL	WBR
Delay (sec/veh)	10.4	297.2	12.6	6.5	291.0	13.4
LOS	B	F	B	A	F	B
v/c Ratio	0.22	1.40	0.30	0.23	1.39	0.32
95%ile Queue (veh)	0.86	10.83	1.25	0.90	12.10	1.40
Approach Delay (sec/veh)	-	136.1		-	133.8	
Approach LOS	-	F		-	F	

6.3 Third Intersection:
The results of HCS-2010 program showed that the left-turn of the minor-street has a delay of 346.7 sec/veh with LOS-F and an oversaturated flow (v/c) of 1.52. The results of Synchro-10 revealed that the delay of the left-turn of the minor-street is 350.3 sec/veh with LOS-F and an oversaturated flow of 1.53. The analysis results have also shown that the minor approach suffers from a high delay with an overall delay of 139.4 sec/veh and LOS-F in HCS-2010 program. On the other hand, Synchro-10 result indicated that the overall delay of the minor approach is 141.1 sec/veh with LOS-F. The results are summarized in Table 4.

Table 4. Evaluation Results of the Third Intersection

	HCS-2010			Synchro-10		
Approach	Major LT	Minor LT	Minor RT	Major LT	Minor LT	Minor RT
	EBL	SBL	SBR	EBL	SBL	SBR
Delay (sec/veh)	11.0	346.7	13.4	9.6	350.3	14.4
LOS	B	F	B	A	F	B
v/c Ratio	0.34	1.52	0.39	0.34	1.53	0.42
95%ile Queue (veh)	1.52	12.22	1.86	1.50	13.10	2.10
Approach Delay (sec/veh)	-	139.4		-	141.1	
Approach LOS	-	F		-	F	

6.4 Fourth Intersection

The analysis results revealed that the minor-street left-turn has a delay of 105.4 sec/veh with LOS-F and an undersaturated flow with 0.90 v/c ratio and a delay of 106.0 sec/veh with LOS-F and an undersaturated flow with 0.91 in both HCS-2010 and Synchro-10 programs respectively. The analysis results also proved that the minor approach suffers from a high delay of 61.5 sec/veh and LOS-F in HCS-2010 Program. However, Synchro-10 result indicated that the overall delay of the minor approach is 61.8 sec/veh with LOS-F, too. The results are summarized in Table 5.

Table 5. Evaluation Results of the Fourth Intersection

	HCS-2010			Synchro-10		
Approach	Major LT	Minor LT	Minor RT	Major LT	Minor LT	Minor RT
	EBL	SBL	SBR	EBL	SBL	SBR
Delay (sec/veh)	9.6	105.4	10.7	6.4	106.0	11.2
LOS	A	F	B	A	F	B
v/c Ratio	0.20	0.90	0.16	0.20	0.91	0.17
95%ile Queue (veh)	0.76	6.42	0.59	0.80	7.30	0.60
Approach Delay (sec/veh)	-	61.5		-	61.8	
Approach LOS	-	F		-	F	

The evaluation results of the fourth intersection were manually validated and simulated using VISSIM-11 software as shown in Fig. 5.

Figure 5. Simulation of the Forth Intersection Using VISSIM-11

The results of the manual analysis and VISSIM simulation were very close to the results of HCS-2010 and Synchro-10 Programs. Table 6 shows the results of the Manual analysis and VISSIM-11 simulation tool.

Table 6. Manual and VISSIM-11 Analysis Results

	VISSIM-11			Manual Analysis		
Approach	Major LT	Minor LT	Minor RT	Major LT	Minor LT	Minor RT
	EBL	SBL	SBR	EBL	SBL	SBR
Delay (sec/veh)	5.4	103.3	13.4	9.7	106.8	11.2
LOS	A	F	B	A	F	B
v/c Ratio	-	-	-	0.20	0.91	0.62
Approach Delay (sec/veh)	-	61.5		-	62.4	
Approach LOS	-	F		-	F	

7. Traffic Signal Warranting

At unsignalized intersections, the delay experienced by the minor approach vehicles should be minimized as much as possible. The desired reduction in delay can be achieved by installing of traffic signals to prioritize the traffic movements at these intersections in accordance with warrant 3; Peak Hour Volume. The installation of traffic signals is justified for each intersection depending on the traffic volumes shown previously in Table I. The Synchro-10 Traffic Signal Warrants Program was used to examine the justification of this warrant. The results showed that the first, second, and third intersections are warranted for traffic signals in the existing term. The fourth intersection, however, is only warranted for traffic signal in the short-term. Fig. 6 shows a typical result (for the first intersection) where the intersect point (the green dot) of the traffic volume on both major and minor streets falls above the applicable curve.

Figure 6. Traffic Signal Justification Curve (Warranted)

Fig. 7 shows that the intersection four is not warranted for traffic signal in the existing term as the intersect point (the red dot) of the traffic volumes on both major and minor streets falls below the applicable curve.

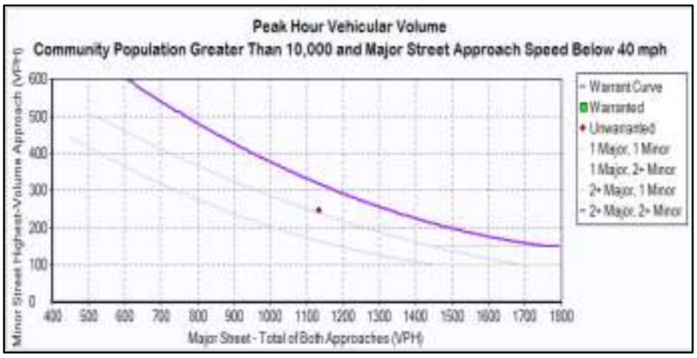

Figure 7. Traffic Signal Justification Curve (Unwarranted)

8. The Improvement

8.1 The Improvements in the Existing Term (2019):

The warranting of the four intersections for traffic signal-control in accordance with warrant 3; Peak Hour Volume has shown that three intersections are warranted for signalization in the existing term except for the fourth intersection which is unwarranted. Justified intersections for signalization need to design a traffic signal cycle time, phases, and the left-turn mode to accommodate the traffic volumes and prioritize the traffic movements passing through these intersections during peak hour periods appropriately to provide a better level of service (LOS) to the users, prevent the conflict and crashes between movements, and consequently, improve safety. Thus, the installation of the traffic signals at these intersections needs to determine the optimum cycle time, phases, and operation mode (lead-lag or split) depending on the geometric design of the intersection, peak hour volumes and composition, approach speed, lane width, grade, etc. [3], [8]. Accordingly, multi cycle times from (60-140) sec. with different lane configurations and operation mode were run and simulated for each left-turn mode. Table 7 presents the selected optimum cycle time with the best Measures of Effectiveness (MOEs) for each intersection and each left-turn operation mode; Protected and Protected-Permitted using Synchro-10 Program (white columns) and validated by HCS-2010 Program (shaded columns).

Table 7. Traffic Signal Cycle Time Performance at Each Intersection (Year, 2019)

Intersection	Major Left-turn mode	Cycle Time (sec)	LOS		Max. v/c		Delay (sec/veh)		Stops (vph)	Fuel used (l/hr)	CO Emission (gr/hr)
1st Int.	Prot.	120	B	B	0.63	0.62	17.2	18.9	1034	98	1820

	Prot.+Perm.	90	B	B	0.68	0.64	12.4	12.9	1006	90	1676
2nd Int.	Prot.	60	B	B	0.69	0.68	18.3	18.7	1192	91	1711
	Prot.+Perm.	60	B	B	0.56	0.52	13.0	12.8	1045	82	1508
3rd Int.	Prot.	70	C	C	0.71	0.74	21.5	21.9	1107	106	1962
	Prot.+Perm.	70	B	B	0.62	0.60	16.4	17.2	966	96	1789

The installation of traffic signals at these intersections combined with prohibiting on-street parking within 250ft (70m) upstream and downstream of intersections [1] and pavement marking will result in better operational performance, minimize the accident rate, and improve safety.

8.2 The Improvements in the Short Term (2024):

Given the growth in traffic volume and the lack of implementation of Transportation Demand Management (TDM) strategies in the short-term in Jordan, the traffic demand on the arterial or collector streets where these intersections are located will also increase. The 5.5% growth factor is used to predict the traffic volume in the short-term period according to equation (1) where; F is the future traffic volume, P is the present traffic volume, g is the growth factor= 5.5%, and n is the number of years in the term= 5 years for short-term period:

$$F = P\,[1+g]^{n} \qquad (1)$$

According to equation (1), each existing traffic volume shown previously in Table I will be multiplied by the term $[1+0.055]^5= 1.307$ to predict the short-term traffic volume. The predicted traffic volumes are shown in Table 8

Table 8. Predicted Traffic Volumes in the Short Term

	Peak Hour Volume PHV (vph)			
Intersection	EB	WB	NB	SB
1st Int.	-	302	2220	
2nd Int.	-	428	1803	
3rd Int.	1460		-	530
4th Int.	1484		-	321

Therefore, the fourth intersection will be warranted and the cycle time of the traffic signal needs to be re-evaluated to accommodate projected traffic volumes. Table 9 shows the selected optimum cycle time for each intersection and operation mode in the short-term period of time (year, 2024)

Table 9. Traffic Signal Cycle Time Performance at Each Intersection (Year, 2024)

Intersection	Major Left-turn mode	Cycle Time (sec)	LOS		Max. v/c		Delay (sec/veh)		Stops (vph)	Fuel used (l/hr)	CO Emission (gr/hr)
1st Int.	Prot.	140	C	C	0.80	0.76	20.9	22.0	1472	138	2566
	Prot.+Perm.	140	B	B	0.80	0.76	16.0	17.2	1260	123	2298

2nd Int.	Prot.	70	C	C	0.83	0.78	26.0	24.6	1727	136	2528
	Prot.+Perm.	60	B	B	0.76	0.68	19.8	17.8	1644	122	2295
3rd Int.	Prot.	80	C	C	0.82	0.81	26.9	27.9	1484	146	2735
	Prot.+Perm.	80	C	C	0.70	0.70	21.4	21.0	1317	134	2509
4th Int.	Prot.	80	C	C	0.64	0.59	20.9	21.2	1241	102	1889
	Prot.+Perm.	70	B	B	0.61	0.56	16.0	18.1	1142	92	1720

The implementation of traffic signals in the existing and short-term periods significantly reduces the overall delay of vehicles from the minor-street in all studied intersections. Fig. 8 presents a bar chart for comparison between the delay experienced by the minor approach vehicles in the existing conditions (with STOP sign) and the existing-term after installation of traffic signals and short-term conditions. Where the maximum existing delay is 172.8 sec/veh and the maximum delay after improvements is 33.3 sec/veh (saving 80.6%) and 44.6 sec/veh (saving 74.2%) in the existing and short-term, respectively.

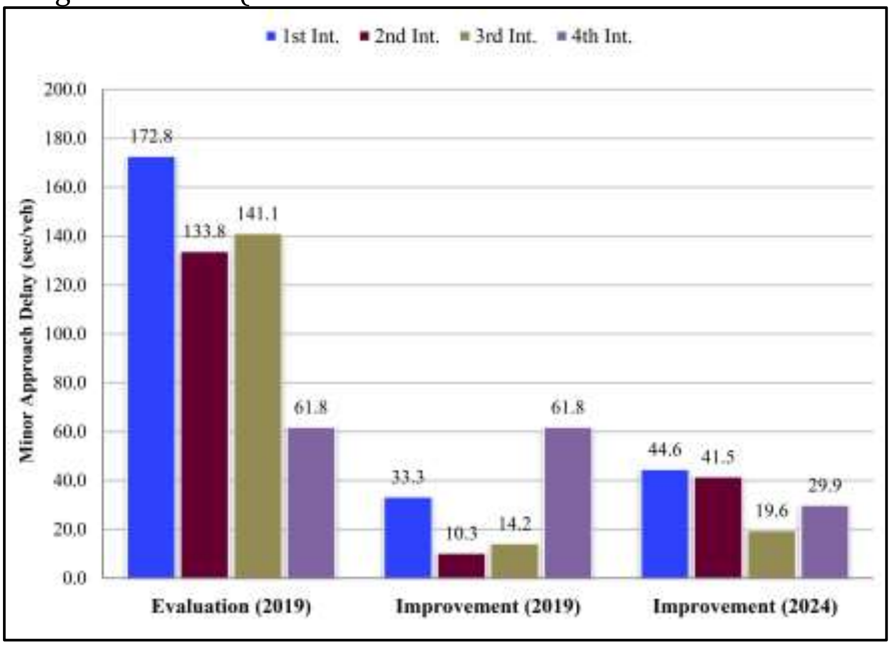

Figure 8. Comparison Bar Chart of the Minor Approach Delay

9. Conclusions

This study presents an evaluation of three-leg unsignalized intersections (Two-Way Stop Control TWSC) due to the limited number of studies focused on this type of intersections. Through this study, several conclusions may be drowned out as follows:

- Applying warrant 3; (Peak Hour Volume) at the selected unsignalized intersections showed that they are warranted for signalization in both existing (2019) and short-term (2024) periods.
- The fourth intersection is not warranted for signalization under warrant 3; (Peak Hour Volume) in the existing term although the minor approach operates with LOS-F. The intersection, however, may be warranted for signalization for the other eight warrants.
- Demand on most urban arterial and urban collector streets forming the selected intersections exceeds the potential capacity of

these streets. This can cause severe congestions at all intersections, particularly during peak periods.

- The traffic volumes passing through theses intersections in the off-peak periods are relatively moderate, therefore, if the protected-permitted left-turn not adopted, and the left-turn is protected only, then the traffic signals should operate in the flashing mode during off-peak periods as recommended by MUTCD.
- A study on Travel Demand Management (TDM) in Amman City is urgently required to reduce traffic demand by at least 10% for the urban roadway network in the medium- and long-term periods of time.
- For medium and long-term periods of time, applying sustainable transportation in Amman City is useful for social, economy, and environment based on the five pillars which are public transportation, electrical or hybrid vehicles, carpooling, bicycles and walking.

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