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The Necessity for a Sustainable Traffic Light System: The Case Study of el-Koura District Traffic Light System

Najib Georges[1], Samer Fawaz[2]
[1]Professor and Chairman of the Civil & Environmental Engineering Department at the University of Balamand
Lebanon
najib.georges@balamand.edu.lb
[2]Lecturer in the Civil & Environmental Engineering Department at the University of Balamand
Lebanon
samer_fawaz@hotmail.com

Abstract **-** Traffic congestion is one of the major problems that Lebanon agonizes from. In this case study, the main objective is to provide a smart traffic light system that can reduce congestion in addition to all of its negative effects. The method used for design was the Webster Method. The results are very favorable. The system was optimized to reduce traffic light stops and idle running times provided that the drivers abide by the speed limit on the roadway and try to maintain a constant speed.

Keywords**:** Traffic, Congestion, Traffic Light System, Webster Method.

1. Introduction

Traffic congestion is a growing problem in many metropolitan areas. Congestion increases travel time, air pollution, carbon dioxide (CO_2) emissions and fuel use because cars cannot run efficiently. The number of hours that drivers waste sitting in traffic is tremendous. Some people point to the growth of traffic congestion as evidence of the need for more infrastructure spending; however, there are ways to manage traffic, particularly at times of peak demand that are relatively inexpensive.

In case study, the emphasis would be on exploring smart traffic light system. The traffic lights selected are located on the main arterial roadway starting in the town of Kfarhazir and ending in the town of Kousba, crossing the capital of the el-Koura District, Amioun, and running through the towns of Kfarsaroun, and Kfaraaqa. Figure 1 provides an overview of the roadway. The selected roadway is a major roadway and very vital to the District (Caza) of el-Koura in North Lebanon. The roadway can be classified as a four-lane two-way urban arterial on a rolling terrain. Traffic congestion on the roadway has major impacts on the economy, environment, and overall life aspects of the surrounding areas.

Fig. 1: Bird Eye View of the Roadway.

The proposed system was designed to minimize the time spent at the intersections. The design was realized to ensure a free flow of traffic all through the roadway. The timing of the traffic lights on the intersections were designed in such a way that once the driver passes a green light at a specific intersection at a constant speed of 50 km/h, he/she will proceed to find all other traffic lights to be green, provided that he/she maintains a constant speed. If the driver tends to decrease or increase the speed, he/she probably might have to stop at the next intersection. This type of traffic light system design can definitely assist to ensure a constant free flow of traffic all through the roadway, at all intersections.

2. Base Line Survey of the Traffic Conditions and Their Effects

Lebanon is a country that is very lagging when it comes to transport, and especially transport management systems. The lack of data collection, in addition to the chaos and negligence that dominates over the sector from the government's side, has led to a much deteriorated condition of the transport sector.

The fact that no national code for roadway and infrastructure design exists, added to mal-practices in the design of all facilities related to the transport sector, in addition to wrong signalization of roadways and intersections, has led to the current traffic situation that Lebanon suffers from. All this is compounded by the mere fact of the exponential increase in the number of vehicles without any growth in the capacity of the roadways.

The lack of awareness and understanding of traffic rules is a common problem in Lebanon. Accidents do happen on a regular basis. These accidents result in a very high fatality and injury rate, in addition to materialistic losses, in terms of working days and hospitalization. Losses due to accidents are estimated to be around 1.5% of the GDP [1]; not to mention that these accidents might result in families losing their main provider(s).

The town of Amioun suffers from traffic jam during rush hours and addition to the fact that a considerable number of drivers do not respect the posted speed limit.

Moreover, traffic congestion is another problem that the region suffers from. The density of passenger vehicles on the roads, in addition to the lack of signalization and infrastructure, has led to a major problem that affects all the lives of the inhabitants. Traffic congestion is estimated to cost Lebanon around 10% of the GDP [1]. The financial losses due to running vehicles stuck in traffic and loss of working hours of the Lebanese work force while waiting in traffic congestions is tremendous [2].

Additionally, the traffic congestion and bad design of the timing of the traffic lights have led to excessive emissions due to burning fuel of idle running vehicles. The air pollution resulting from the transport sector in Lebanon constitutes one of the largest sources of emissions in the country [3].

3. Proposed Solution for the Amioun - Kousba Highway

Since one of the major problems of the investigated roadway is the three major intersections that have been poorly designed, thus resulting in major congestion on the roadway in general and specifically at the intersections, a smart traffic light timing system has been adopted for this case study as a solution. The three traffic lights were designed to provide a continuous flow of traffic.

The cycle length and the timings of the traffic lights were designed so as once the first traffic light turns green, the driver should proceed to the next traffic light only to find it green, where he/she can proceed to the next and so on, provided that the driver maintains a constant speed of 50km/h; therefore, the idle running time of the vehicles is reduced to a minimum.

Since the discussed traffic light design reduces vehicles stops and delays, all the negative effects cited above are reduced. This specific design forces the drivers to drive at a constant speed of 50 km/h, excess speed is reduced, which reduces the accident rates. Additionally, the pollution produced by the vehicles is immensely reduced, since the idle running time is reduced. The financial losses are reduced too, and the time spent to reach the destinations is reduced.

4. Adopted Methodology

Two of the most common methods usually used to calculate the cycle length, the Webster Method and the Highway Capacity Method (HCM) [4]. The Webster Method may be applied to situations unlike the HCM. The HCM is a method that calculates the cycle length based on the highest flow, depending on the effective green time of a certain lane group; however, it was found that when designing the traffic lights for this region, the HCM method may not be applicable. The reason being that using the HCM requires a saturation flow of 1,900 vehicle/hour/lane; however, such a saturation flow cannot be applied to Lebanon, the reason being that the specific variable “h” that is described to be the “time headway” is significantly reduced; the time headway is the interval time between vehicles that are driving in the same direction. Due to Lebanon’s reckless driving the space headway is significantly reduced; therefore, the saturation flow is much higher than

1900 vehicle/hour/lane. As soon as the lights turn green, all the vehicles move at once, not respecting the safe distances between one another.

The saturation flow is given by:

$$S = \frac{3600}{h} \tag{1}$$

where S is the saturation flow [5].

Having very small time headway may cause the saturation flow to be much higher than 1900 vehicle/hour/lane. Lebanon has no study regarding traffic flow patterns and transportation. The best that can be done is an approximation to a country with a similar traffic behavior. After conducting a thorough investigation, it was found that Saudi Arabia had a saturation flow rate of 2500 vehicle/hour/lane. This number seems logical for Lebanon since Lebanese drivers have a similar behavior regarding space headway and traffic light flow.

5. Flow Number Calculation Using the Webster Method

5.1. Average Annual Daily Traffic (Aadt)

5.1.1. Initial Car Count

Several hours were sampled in order to estimate the traffic flow at the three intersections. Vehicles were monitored at each of the three intersections. Then after collecting traffic counts of certain hours on different days, expansion factors were used to estimate the average daily traffic. Since Lebanon lacks in terms of traffic studies and development of factors, factors from the NRA of Dublin were adopted due to many similarities between Lebanon and Dublin in terms of traffic flow behavior. Note that the East and West directions have two lanes in each direction, while the North and South directions have one lane in each direction.

5.1.2. Hourly Traffic Flow (HTF)

After the vehicle count was finalized, Table 1 is used to convert the numbers based on the hours of counts.

Table 1: Hourly Traffic Flow as Proportion of 24-Hour Traffic Flow.

Hour Ending	1:00	2:00	3:00	4:00	5:00	6:00
Greater Dublin area	0.008	0.005	0.003	0.004	0.006	0.017
Major inter Urban (Excl. GDA)	0.009	0.005	0.004	0.004	0.006	0.013
West and South west	0.007	0.004	0.002	0.002	0.003	0.003
All other areas	0.007	0.004	0.003	0.003	0.004	0.011
Hour Ending	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**
Greater Dublin area	0.049	0.072	0.073	0.059	0.053	0.054
Major Inter Urban (Excl. GDA)	0.030	0.064	0.077	0.062	0.055	0.057
West and South west	0.021	0.062	0.073	0.060	0.056	0.059
All other areas	0.026	0.060	0.070	0.061	0.056	0.059
Hour Ending	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
Greater Dublin area	0.056	0.058	0.061	0.068	0.079	0.085
Major Inter Urban (Excl. GDA)	0.060	0.063	0.065	0.071	0.082	0.090
West and South west	0.062	0.063	0.065	0.071	0.081	0.089
All other areas	0.064	0.067	0.070	0.075	0.084	0.090
Hour Ending	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**	**24:00**
Greater Dublin area	0.074	0.056	0.041	0.032	0.023	0.014
Major Inter Urban (Excl. GDA)	0.074	0.054	0.041	0.031	0.022	0.014
West and South west	0.075	0.054	0.039	0.030	0.021	0.013
All other areas	0.073	0.055	0.041	0.031	0.021	0.012

5.1.3. Average Annual Daily Traffic (AADT) Calculation

The HTF is then adjusted using Table 2 in order to obtain the Daily Flow Indices (DFI). Next, the AADT is calculated by multiplying the DFI by the Monthly Flow Indices (MFI) from Table 3 depending on the month.

Table 2: Daily Flow Indices.

Day	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**
Proportion of WADT	0.99	1.02	1.03	1.07	1.15	0.91	0.86
Index	1.01	0.98	0.97	0.93	0.87	1.10	1.16

Table 3: Monthly Flow Indices.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Proportion of AADT	0.94	0.94	0.96	1.02	1.03	1.04
Index	1.06	1.06	1.04	0.98	0.97	0.96
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Proportion of AADT	1.06	1.06	1.04	1.01	0.96	0.96
Index	0.94	0.93	0.96	0.99	1.04	1.04

5.2. Flow Numbers

5.2.1. Calculating Design Hourly Volume (DHV)

The DHV is calculated as 8 to 12 percent of the AADT. In urban regions, it is preferred that the maximum percent be taken. Therefore, AADT is multiplied by 0.12 in order to obtain the DHV.

5.2.2. Calculating DHV (including Trucks)

While counting vehicles along the Amioun main road, it was noted that approximately 7% of the total vehicles were trucks. Following the rules of the Webster method, 1 truck is considered equivalent to 1.6 passenger cars.

Therefore, to obtain the total DHV, apply the following formula:

Total DHV = DHV + 0.07 × DHV × 1.6

5.2.3. Calculating Equivalent Straight-Through Passenger Cars (ESTP)

The ESTP for the lanes that do not include left turns are equal to the Total DHV. As for all lanes that include left turns, the DHV for the left turning vehicles is multiplied by 1.4.

5.2.4. Flow Numbers

For each lane, the Flow Number = Sum of the ESTP for all directions, as shown in Tables 4, 5, and 6.

Table 4: Intersection 1 Flow Number Calculations.

	NS	**NW**	**NE**	**SN**	**SE**	**SW**
Intersection 1	5	6	7	246	94	37
HTF	39.1	46.9	54.7	1921.9	734.4	289.1
WEF	38.7	46.4	54.1	1902.8	727.1	286.2
AADT	40.3	48.3	56.4	1982.1	757.4	298.1
DHV	4.8	5.8	6.8	237.9	90.9	35.8
DHV (7% trucks x 1.6)	6	7	8	265	102	39.8
ESTP	6	7	12	265	102	56
Flow #	250			423		
	WE	**WS**	**WN**	**EW**	**EN**	**ES**
Intersection 1	19	625	144	771	2	202
HTF	148.4	4882.8	1125	6023.4	15.6	1578.1
WEF	147	4834.5	1114	5963.8	15.5	1562.5
AADT	153.1	5036	1160	6212.3	16.1	1627.6
DHV	18.4	604.3	139	745.5	1.9	195.3
DHV (7% trucks x 1.6)	21.0	672.0	155	829	3	217.2
ESTP	21.0	672.0	217	829	3	305
Flow #	693		217	832		

	INT. 1	HTF	WEF	AADT	DHV	DHV (7%)	ESTP
TOTAL	2158	16859.4	16692.5	17388	2086 .6	2320.3	2495.0

Table 5: Intersection 2 Flow Number Calculations.

	NS	**NW**	**NE**	**SN**	**SE**	**SW**
Intersection 2 (+4.3 km)	59	268	271	19	72	89
HTF	460.9	2093.8	2117	148.4	562.5	695.3
WEF	456.4	2073	2096	147	557	688.4
AADT	475.4	2159	2183	153.1	580.1	717.1
DHV	57	259.1	262	18.4	69.6	86.1
DHV (7% trucks x 1.6)	64	289	292	21	78	96
ESTP	64	289	409	21	78	135
Flow #	762			234		
	WE	**WS**	**WN**	**EW**	**EN**	**ES**
Intersection 2 (+4.3 km)	184	815	8	809	184	46
HTF	1437	6367.2	62.5	6320.3	1437	359.4
WEF	1423	6304	61.9	6257.7	1423	355.8
AADT	1482	6567	64.5	6518	1482	370.6
DHV	178	788	7.7	782.2	177.9	44.5
DHV (7% trucks x 1.6)	198	877	9	870	198	70
ESTP	198	877	13	870	198	70
Flow #	1075		13	1068		70

	INT. 2	HTF	WEF	AADT	DHV	DHV (7%)	ESTP
TOTAL	2824	22062.5	21844.1	22754.2	2730.5	3036.3	3222

Table 6: Intersection 3 Flow Number Calculations.

	NS	**NW**	**NE**	**SN**	**SE**	**SW**
Intersection 3 (+2.1 km)	184	130	131	81	113	74
HTF	1437.5	1015.6	1023	632.8	882.8	578.1
WEF	1482	1047	1055	652.4	910.1	596
AADT	1543.7	1090.7	1099	679.6	948	620.8
DHV	185.2	130.9	132	81.5	113.8	74.5
DHV (7% trucks x 1.6)	206	146	147	91	127	83
ESTP	206	146	206	91	127	117
Flow #	558			335		
	WE	**WS**	**WN**	**EW**	**EN**	**ES**
Intersection 3 (+2.1 km)	107	1004	97	131	130	184
HTF	835.9	7843.8	758	1023.4	1015	1437
WEF	861.8	8086.3	781	1055.1	1047	1482
AADT	897.7	8423.3	813	1099.1	1090	1543
DHV	107.7	1010.8	97.7	131.9	130.9	185.2
DHV (7% trucks x 1.6)	120	1125	109	147	146	206
ESTP	120	1125	153	147	146	289
Flow #	1245		153	293		289

	INT. 3	HTF	WEF	AADT	DHV	DHV (7%)	ESTP
TOTAL	2366	18484.4	19056.1	19850.1	2382	2648.8	2873

6. Configuring Traffic Lights

6.1. Calculating Saturation Flow Rate

The saturation flow rate calculations were performed according to the various configurations as shown in Figure 2 [4,6]. The adjustment factors used for computing the saturation flow rate are obtained from Table 7. Note: If the road consists of one lane, all directions are combined in one saturation flow. If it consists of several lanes, the saturation flow for each lane is computed:

$$s = s_o \text{ x } N \text{ x } f_w \text{ x } f_{HV} \text{ x } f_g \text{ x } f_p \text{ x } f_{bb} \text{ x } f_a \text{ x } f_{LU} \text{ x } f_{LT} \text{ x } f_{RT} \text{ x } f_{Lpb} \text{ x } f_{Rpb} \tag{2}$$

s = saturation flow rate for the subject lane group expressed as a total for all lanes in the lane group (veh/h), taken as 2500 [7].

f_p= adjustment factor for the existence of a parking lane and parking activity adjacent to the lane group

f_{bb}= adjustment factor for the blocking effect of local buses that stop within the intersection area

f_{Rpb} = pedestrian > bicycle adjustment factor for right-turn movements

f_{Lpb} = pedestrian adjustment factor for left-turn movements

f_{RT} = adjustment factor for right turns in the lane group

f_{LT} = adjustment factor for left turns in the lane group

f_{LU} = adjustment factor for lane utilization

f_a = adjustment factor for area type

f_g = adjustment factor for approach grade

f_{HV} = adjustment factor for heavy vehicles in the traffic stream
f_w = adjustment factor for lane width
N = number of lanes in the group
s_o = base saturation flow rate per lane pc/hr/lane

Table 7: Adjustment Factors for Saturation Flow Rates [4].

Factor	*Formula*	*Definition of Variables*	*Notes*
Lane width	$f_w = 1 + \frac{(W-12)}{30}$	W = lane width (ft)	$W \geq 8.0$ If $W > 16$, two-lane analysis may be considered
Heavy vehicles	$f_{HV} = \frac{100}{100 + \%HV(E_T - 1)}$	$\% HV$ = percent heavy vehicles for lane group volume	$E_T = 2.0$ pc/HV
Grade	$f_g = 1 - \frac{\%G}{200}$	$\% G$ = percent grade on a lane group approach	$-6 \leq \% G \leq +10$ Negative is downhill
Parking	$f_p = \frac{N - 0.1 - \frac{18N_m}{3600}}{N}$	N = number of lanes in lane group N_m = number of parking maneuvers/h	$0 \leq N_m \leq 180$ $f_p = \geq 0.050$ $f_p = 1.000$ for no parking
Bus blockage	$f_{bb} = \frac{N - \frac{14.4N_B}{3600}}{N}$	N = number of lanes in lane group N_B = number of buses stopping/h	$0 \leq N_B \leq 250$ $f_{bb} = \geq 0.050$
Type of area	$f_a = 0.900$ in CBD $f_a = 1000$ in all other areas		
Lane utilization	$f_{LU} = v_g/(v_{g1}N)$	v_g = unadjusted demand flow rate for the lane group, veh/h v_{g1} = unadjusted demand flow rate on the single lane in the lane group with the highest volume N = number of lanes in the lane group	
Left turns	Protected phasing: Exclusive lane: $F_{LT} = 0.95$ Shared lane: $f_{LT} = \frac{1}{1.0 + 0.05P_{LT}}$	P_{LT} = proportion of LTs in lane group	See pages 474 through 483 for non-protected phasing alternatives
Right turns	Exclusive lane: $f_{RT} = 0.85$ Shared lane: $f_{RT} = 1.0 - (0.15)P_{RT}$ Single lane: $f_{RT} = 1.0 - (0.135)P_{RT}$	P_{RT} = proportion of RTs in lane group	$f_{RT} = \geq 0.050$
Pedestrian-bicycle blockage	LT adjustment: $f_{Lpb} = 1.0 - P_{LT}(1 - A_{pbT})(1 - P_{LTA})$ RT adjustment: $f_{Rpb} = 1.0 - P_{RT}(1 - A_{pbT})(1 - P_{RTA})$	P_{LT} = proportion of LTs in lane group A_{pbT} = permitted phase adjustment P_{LTA} = proportion of LT protected green over total RT green P_{RT} = proportion of RTs in lane group P_{RTA} = proportion of RT protected green over total RT green	See pages 485 to 490 for step-by-step procedure

[a]The table contains formulas for all adjustment factors. However, for situations in which permitted phasing is involved, either by itself or in combination with protected phasing, separate tables are provided, as indicated in this exhibit.

6.2. Calculating Traffic Light Time

6.2.1. Amber Light Duration

The amber light duration is calculated for each of the lanes (as performed for saturation). It includes several variables:

$$\tau = \frac{W+20}{U0\times1.47} + \frac{U0\times1.47}{2\times(a+\delta\times32.2)} \tag{3}$$

Round-up value to nearest 0.5.

6.2.2. Ratios of Approach

The formula used is simply

$$Y = \frac{q}{s} \tag{4}$$

6.2.3. Optimum Cycle Length (C_0)

The procedure to calculate the optimum cycle length is as follows [8]:

a. Take max Y from east and west, and take the max between North and South (due to low density)

b. Divide each Y_{max} by the sum of all the Y_{max}

c. C_0 = (1.5 × sum of l_i + 5) / (1 – sum of Y_{max}), l_i is the lost time per phase, normally equal to 3.5 s

d. Round C_0 up to nearest integer

6.2.4. Actual Green Light Duration (G_{ai})

Procedure is as follows [10]:

a. G_{te} = Rounded C_0 – L

b. G_{ei} = G_{te} × (Y_i / (sum of Y_i)

c. G_{ai} = G_{ei} + l_i – τ (rounded)

6.2.5. Additional Notes

The red light duration is the remainder of the cycle time C_0.

Also the cycle at the next intersection begins after time = distance / U_0.

6.3. Configurations Analyzed

The following configurations were chosen due to the vehicles count. The East and West directions are very dense in terms of vehicles per hour, while the North and South directions are relatively low.

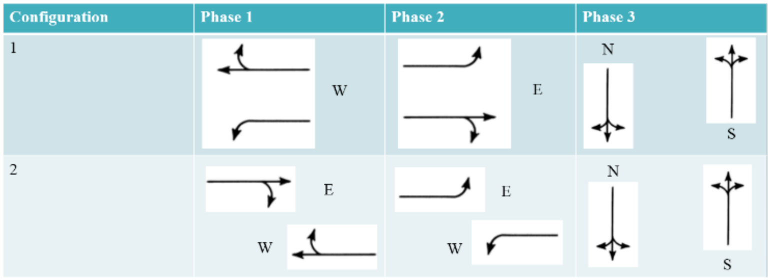

Fig. 2: Different Configurations Considered.

Configuration 1 includes:

Phase 1: All western lanes (lanes coming from West) move together

Phase 2: All eastern lanes move together

Phase 3: All northern and southern lanes move together (and so it repeats)

Configuration 2 includes:

Phase 1: Eastern and western lanes move together, only the straight and right traffic
Phase 2: The left directions of the eastern and western lanes move together
Phase 3: All northern and southern lanes move together (and so it repeats)

7. Final Representation of Design

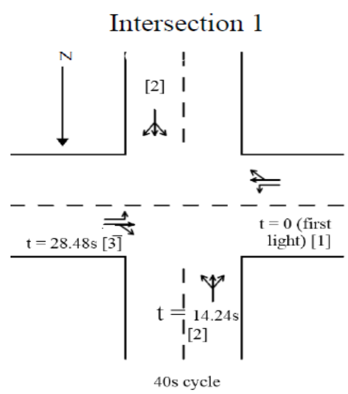

Fig. 3: Timings of Intersection 1.


Fig. 4: Plan View of Intersection1.

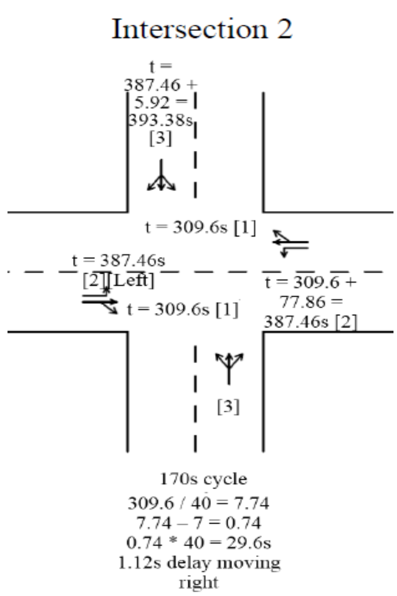

Fig. 5: Timings of Intersection 2.

Fig. 6: Plan view of Intersection2.

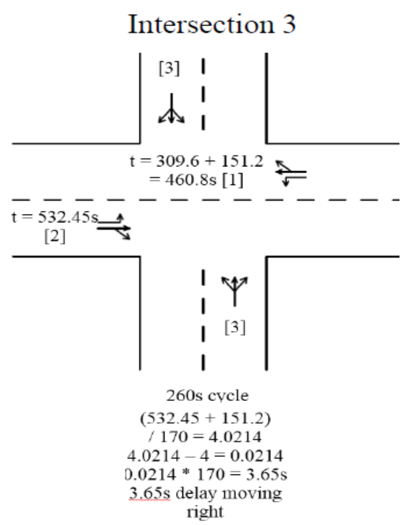

Fig. 7: Timings of Intersection 3.

Fig. 8: Plan View of Intersection 3.

- Travel time from Intersection 1 to 2 = (4.3km*3600km/hr)/(50 km/hr) = 309.60 s
- Travel time from Intersection 2 to 3 = (2.1km*3600km/hr)/(50 km/hr) = 151.20 s

The above figures show specifically at what time each intersection starts. Starting with the first intersection and the first traffic light at t = 0 as per Figures 3 and 4, the second phase will begin after 14.24 seconds and the third phase at 28.48 seconds. The distance between the first and second intersection is 4.3 km, so at a 50 km/h speed, the driver will reach the second intersection after 309.60 seconds, which is when the first phase at the second intersection turns green, as per Figures 5 and 6. The second phase of the second intersection (which is the two left turns) turns green after 77.86 seconds, giving a grand total of 387.46 seconds from the first intersection. The third phase turns green after 5.92 seconds, giving a grand total of 393.38 seconds. The distance between the second intersection and the third intersection is 2.1 km, so at 50 km/h speed, the driver will reach the third intersection after 151.20 seconds giving a grand total of 460.80 seconds, as per Figures 7 and 8. The second and third lights turn green after 74.17 seconds and 37.80 seconds, respectively.

At this stage the objective was to decide the sequence of the phases to reduce delays from every possible phase. The reason the first intersection is chosen like this will be explained later. For intersection 2, the different sequences will not cause that much of a difference since the left turn time is very small due to the low vehicle volume; however, for intersection 3, it makes a huge difference to choose N/S phase before the East going West phase. The reason being that, if a car coming from the first intersection decides to make a U-turn at the last intersection and the N/S is the second phase, the driver will be delayed 25 seconds by calculation; however if the East going West phase is the second phase, the driver will be delayed 3.65 seconds. Now, for the first intersection, the N/S phase was chosen to be the second because this causes the third phase to begin at 28.48 seconds. By calculations, the driver arrives at the traffic light at 29.60 seconds which means there are no delays.

Additional Lane per Direction - The parking lanes from the edges of the street were removed to increase the number of lanes (geometric change). These parking lanes are used by vehicles going into the commercial shops. As a result of this mitigation measure, parking provisions should be provided on the back streets.

8. Conclusions and Recommendations

After performing this study, there are many conclusions that may be drawn. First, the HCM method cannot be used in Lebanon due to the overpopulation of vehicles compared to the roads. This method requires such a low saturation that it cannot apply to most middle eastern countries, as such, no configuration will be acceptable. This leads to the next conclusion: Roadways in the Koura District in their current condition are not wide enough to handle these high densities of cars. Finally, a smart system for traffic management can have a very large impact on the lives of the inhabitants of the District.

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