Optimum Cycle Time for N-Leg Intersection on Real-Time the Case of Uncongested Traffic Flow

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***Abstract*—One of the solutions to control the delay and congestion of intersections in large cities is through the development of an intelligent traffic control system which is based on the measurement of actual traffic flow on real-time. Typically, the control system is an unadjustable and limited to maximize the traffic flow which resulted to traffic congestions. Therefore, to measure effectively and dynamically the actual traffic flow on real-time in any geometric characteristics the Optimum Cycle Time Method is vital to determine all the traffic movements with different geometric conditions. This method dynamically calculate all the possible cycling time according to existing and to approaching traffic volume of intersection collected from intelligent traffic camera; maximize the capacity of each phase at optimum cycle on real time; and minimize the delay as well as the congestion degree of intersection.**

***Index Terms*—cycle arrangement, cycle time, delay, optimum cycle, real-time, uncongested**

I. Introduction

There are two types of control for intersection: the Signalized and the Un-Signalized Intersection. Stop light used to avoid conflict between the movements; to increase the capacity of intersection; and to make the intersection safer.

Stop signal is regarded as the ultimate form of at-grade intersection control due to the fact that it can greatly reduce the number and nature of intersection conflicts as no other form of control can.

But, based on the MUTCD (Manual Uniform of the Timing Control Devices) the traffic signal control systems also have advantages and disadvantages as well, as enumerated [1].

Advantages:

- Provides orderly movement of traffic.
- Increases traffic-handling capacity of intersection if proper physical layouts and control measures are used; and if the signal timing is reviewed/ updated on a regular basis to ensure that it satisfies the current traffic demands.
- Reduces frequency and severity of certain types of crashes.
- Coordinates to provide continuous or nearly continues movement at a definite speed along a given route under favorable condition.
- Uses to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross.

Disadvantages:

- Excessive delay.
- Excessive disobedience of signal indication.
- Increase use of less adequate routes as road users attempt to avoid the traffic control signal.
- Significant increase in the frequency of collision.

Since, the intersection is the bottleneck in the urban street network the stop light must designed according to current flow of traffic or movements which will be the critical task of the traffic engineers to know-how to manage the conflicts occurred at intersections in a manner that ensures safety and provides for efficient movement through the intersection for both motorists and pedestrians in consideration of the discussed advantages and disadvantages of the traffic signal control system.

Therefore, to determine the best cycle of intersection and to optimize the traffic parameter the following steps are required:

Step1. Conflict Analysis: conflict between each movement should be analyzed. And, to analyze the conflict the type and the number of conflict between movements must be recognized (Diverging, Merging and Crossing) [2].

Step2. Phase Generation: Generate all possible phases by combination of movements at intersection without conflicting to each other (Merging and Crossing).

Step3. Determination of Cycle Pattern and Optimum Cycle Time: Combine the possible phases of intersection to create all possible cycle; and to calculate the cycle time and other traffic parameter such as delay, capacity and degree of congestion. Efficiently studies the result will drive to choose the best cycle with minimum delay [3].

II. Conflict Analysis

To determine the type of conflict between any two movements at any geometric shape with *N* number of leg intersections should analyze the approaching angles and exit angles of two movements.

The succeeding algorithm shows the steps on how to determine the type of conflict between two movements.

Determination of the Type of Conflict:

Consider the two movements; M1 & M2 are the name of approach angles of each movement as α1 and α2 as well $\beta 1$ and $\beta 2$ for exit angles of two movements.

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Step1. Check the degree between M1 and M2.

Step2. If $\Delta\alpha$ (α2-α1) is zero degree but $\Delta\beta$ (β2-β1) change to any positive or negative degree count it as Diverging.

Step3. If $\Delta\alpha$ (α2-α1) is any positive or negative degree but$\Delta\beta$ (β2-β1) change to zero degree counts it as Merging.

Step4. If any positive or negative change in approach $\Delta\alpha$ (α2-α1) degree with exit $\Delta\beta$ (β2-β1) degree of M1 and M2 count it as Crossing.

Step5. If none of the above considers it has no conflict.

By using the above algorithm, all types of conflicts between all movements in intersection can be recognized.

The number of conflict in intersection is depends to number of intersection leg. Therefore, using the following formulas the total number of each conflict can be calculated:

$$Nm = Nd = n(n-2) \tag{1}$$

$$Nc = n^2(n-1) \times \frac{n-2}{6} \tag{2}$$

As shown in Table I, all number of Merging, Diverging, Crossing and total conflict for 3 to 8 Leg intersections are calculated and summarized in Table I:

TABLE I. TOTAL NUMBER OF CONFLICT IN N-LEG INTERSECTION

	Merging	Diverging	Crossing	Total
3 Leg	3	3	3	9
4 Leg	8	8	16	32
5 Leg	15	15	50	80
6 Leg	24	24	120	168
7 Leg	35	35	245	315
8 Leg	48	48	448	544

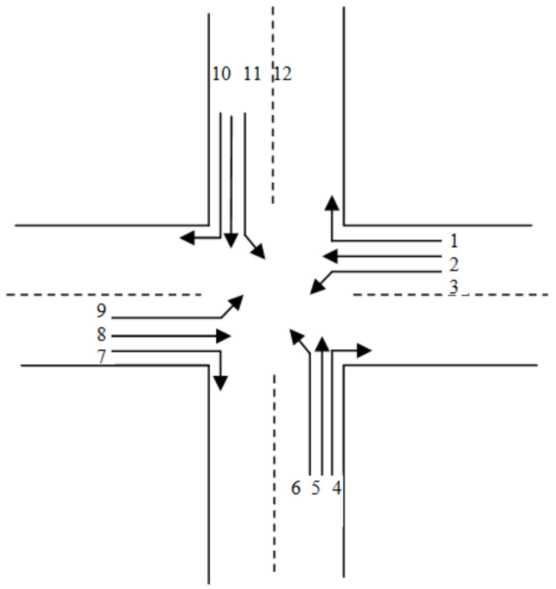

Figure 1. View of 4-leg intersection

Based in the Table I computation, it is now possible to construct conflict matrix and to prepare possible movement table.

Each of the twelve possible movements at a 4-leg intersection is numbered according the Fig. 1.

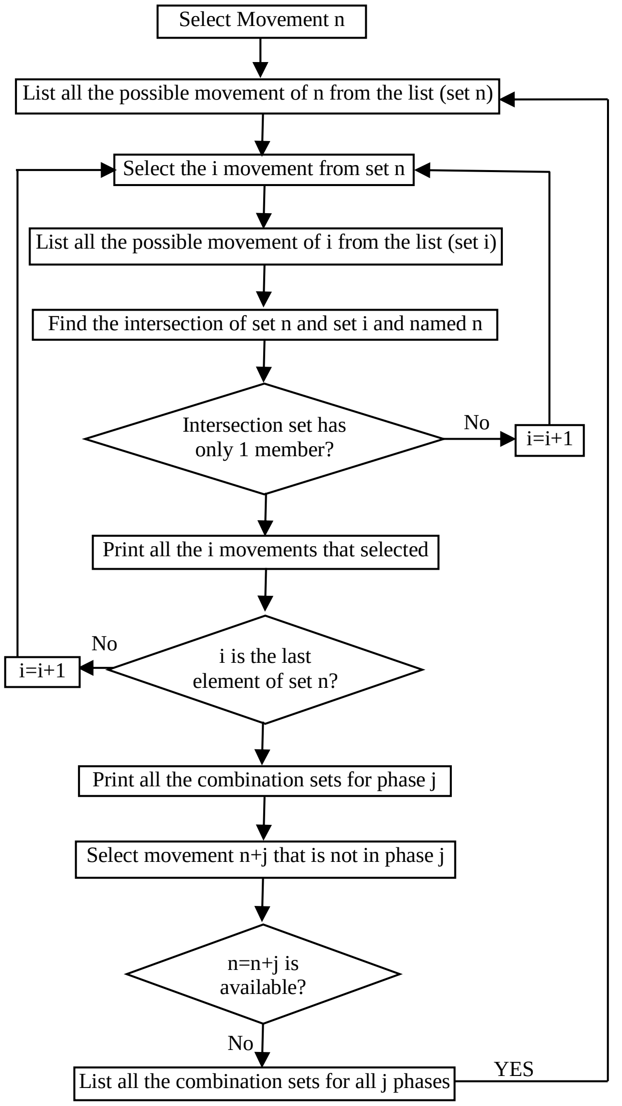

Figure 2. Flow chart of creating phases using possible movement

The conflict matrix and the possible movement of 4-Leg intersections as a specimen are tabulated and summarized in Table II and Table III:

TABLE II. CONFLICT MATRIX FOR 4- LEG INTERSECTION

	1	2	3	4	5	6	7	8	9	1	1	1
1	-	D	D	N	M	N	N	N	M	N	N	N
2	D	-	D	N	C	M	N	N	C	M	C	C
3	D	D	-	N	C	C	M	C	N	N	M	C
4	N	N	N	-	D	D	N	M	N	N	N	M
5	M	C	C	D	-	D	N	C	M	N	N	C
6	N	M	C	D	D	-	N	C	C	M	C	N
7	N	N	M	N	N	N	-	D	D	N	M	N
8	N	N	C	M	C	C	D	-	D	N	C	M
9	M	C	N	N	M	C	D	D	-	N	C	C
1	N	M	N	N	N	M	N	N	N	-	D	D
1	N	C	M	N	N	C	M	C	C	D	-	D
1	N	C	C	M	C	N	N	M	C	D	D	-

TABLE III. POSSIBLE MOVEMENT WITHOUT CONFLICT FOR EACH AVAILABLE MOVEMENT IN 4-LEG INTERSECTIONS

Movement	Possible Movement
1	2,3,4,6,7,8,10,11,12

2	3,4,7,8,1
3	4,9,10,1,2
4	5,6,7,9,10,11,1,2,3
5	6,7,10,11,4
6	7,12,1,4,5
7	8,9,10,12,1,2,4,5,6
8	9,10,1,2,7
9	10,3,4,7,8
10	11,12,1,3,4,5,7,8,9
11	12,1,4,5,10
12	1,6,7,10,11

III. Phase Generation of Signalized Intersection

After the determination of the types and numbers of conflict in N-Leg Intersection; and, the preparation of conflict matrix and possible movement table the combination of the movement without conflict with each other can now apply to prepare the possible phases using the flow chart shown below:

Therefore, using the flowchart in Fig. 2 all the possible phases without conflict in Merging and Crossing can be easily enumerated as shown below in Table IV.

TABLE IV. All Possible Phases In 4-Leg Intersection

1,2,3,4	1,4,10,11	4,5,10,11
1,2,4,7	1,6,7,12	4,5,6,7
1,2,7,8	1,7,8,10	4,5,7,10
1,3,4,10	1,7,10,12	4,7,9,10
1,4,6,7	1,10,11,12	7,8,9,10
1,4,7,10	3,4,9,10	

IV. Determination of Phase Pattern & Optimum Cycle Time

For instant, based tot he listed possible phases as discussed and shown earlier, the combination of all possible phases are vital to determine the 114,240 possible complete cycles for 4-Leg Intersection.

TABLE V. Required Data

Type of Data	Parameter
Geometric conditions	Area type Number of lanes Average lane width Grade Existence of exclusive LT or RT lanes Length of storage bay, LT or RT lane
Traffic conditions	Demand volume by movement Base saturation flow rate Peak-hour factor Percent heavy vehicles Approach pedestrian flow rate Bus/ Taxi stopping at intersection Parking activity Arrival type Proportion of vehicles arriving on green Approach speed

Then, after the determination of all possible phases and completion of the cycles of N-Leg Intersection the traffic data and the geometric condition of intersection as listed in Table V, can be incorporated to estimate the initial green time of each possible cycle [4] as represented in Fig. 3.

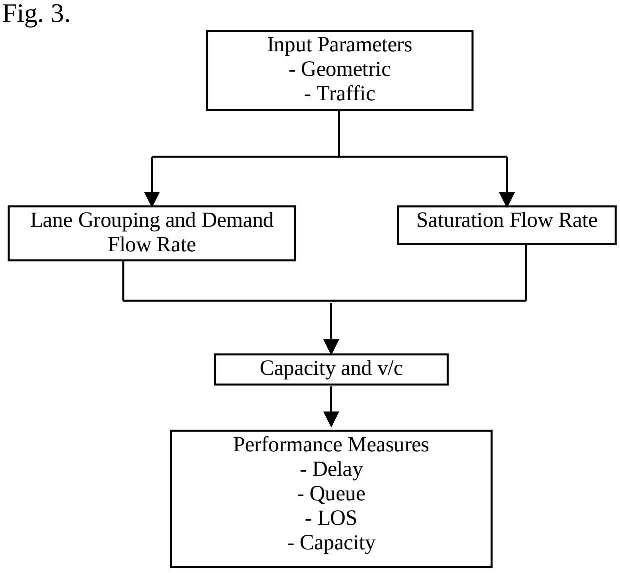

Figure 3. Signalized intersection methodology

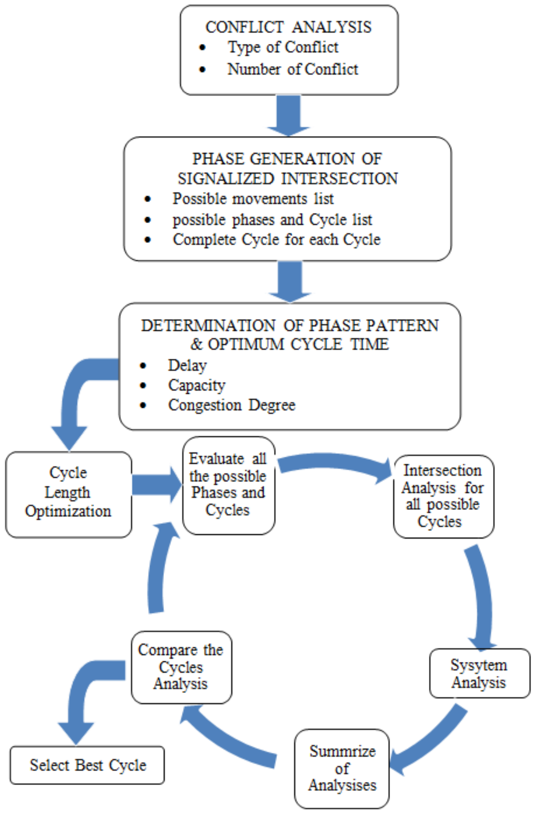

Figure 4. Optimizing cycle time process

After the estimate, based on the Y-Value of the critical movement of each complete cycle the initial green time cycle can now be calculate the green time cycle; the capacity of each movement; the delay of each movement; and the congestion degree of intersection. Therefore, based on the calculated traffic parameters of each movement the phase and the cycle performance of each cycle can be possibly optimized and the best cycle for the existing traffic can be selected.

Before the completion of each cycle the real-time traffic of intersection and the approaching traffic flow to the intersection can be estimated by using *Intelligent Traffic Camera.*

The real-time traffic of intersection must be integrated to the method to calculate the cycle time of all possible complete cycles; to select the optimum cycle; to maximize the capacity; to minimize the delay of critical movements; and to lessen the congestion degree of intersection as shown in Fig. 4.

To all the red time at the last phase of the cycle the method will modify the cycle pattern and adjust the traffic light timing to the selected optimum cycle based on the real-time traffic condition and to the flow of intersection.

V. CASE STUDY

To further illustrate the significant of this study, the simulation 4-leg isolated intersection with various is recommended which will be discussed to clearly understand and to appreciate the calculation of optimum cycle time, the traffic parameters of movements and the intersection on real-time traffic data.

Saturation Flow and the three various Volume Flow considered in simulated case study are listed in Table VI [5].

TABLE VI. TRAFFIC DATA OF 4-LEG INTERSECTION

Movement	**Volume pcu/hr**			**Saturation Flow**
	Case 1	**Case 2**	**Case 3**	
1	150	50	450	3500
2	200	500	600	3500
3	200	25	550	3500
4	75	185	250	3000
5	340	700	400	3000
6	1000	220	500	3000
7	150	70	300	3500
8	600	610	450	3500
9	500	35	350	3500
10	50	175	300	3000
11	310	800	550	3000
12	700	250	600	3000

Calculated Traffic Parameters of each various conditions of case study are shown in Table VII, Table VIII and Table IX.

TABLE VII. CYCLE PATTERN AND TRAFFIC PARAMETER OF INTERSECTION CASE 1

Phase	Movement	Volume	SFR	Y value	Green time	Capacity	Delay	Congestion
I	1	150	3500	0.043	37	350	38.08	0.821
	6	1000	3000	0.333		300	54.68	
	7	150	3500	0.043		350	38.08	
	12	700	3000	0.233		300	47.54	
II	2	200	3500	0.057	6	622	32.27	
	3	200	3500	0.057		622	32.27	
	4	75	3000	0.025		533	31.20	
	1	150	3500	0.043		622	31.78	
III	5	340	3000	0.113	12	1000	22.56	
	10	50	3000	0.017		1000	20.34	
	11	310	3000	0.103		1000	22.30	
	4	75	3000	0.025		1000	20.51	
IV	8	600	3500	0.171	19	739	33.80	
	9	500	3500	0.143		739	32.67	
	10	50	3000	0.017		633	28.48	
	7	150	3500	0.043		739	29.26	

TABLE VIII. CYCLE PATTERN AND TRAFFIC PARAMETER OF INTERSECTION CASE 2

Phase	Movement	Volume	SFR	Y value	Green time	Capacity	Delay	Congestion
I	1	50	3500	0.014	18	819	22.32	0.745
	2	500	3500	0.143		819	25.67	
	7	70	3500	0.020		819	22.45	
	8	610	3500	0.174		819	26.65	
II	3	25	3500	0.007	6	290	31.77	
	9	35	3500	0.010		290	31.87	
	10	175	3000	0.058		248	33.50	
	4	185	3000	0.062		248	33.62	
III	4	185	3000	0.062	27	1074	16.47	
	5	700	3000	0.233		1074	20.16	
	10	175	3000	0.058		1074	16.41	
	11	800	3000	0.267		1074	21.08	
IV	6	220	3000	0.073	8	336	31.92	
	7	70	3500	0.020		392	30.18	
	12	250	3000	0.083		336	32.27	
	1	50	3500	0.014		392	30.01	

TABLE IX. CYCLE PATTERN AND TRAFFIC PARAMETER OF INTERSECTION CASE 3

Phase	Movement	Volume	SFR	Y value	Green time	Capacity	Delay	Congestion
I	1	450	3500	0.129	17	678	33.56	0.811
	2	600	3500	0.171		678	35.30	
	3	550	3500	0.157		678	34.70	
	4	250	3000	0.083		581	31.91	
II	5	400	3000	0.133	19	617	32.77	
	6	500	3000	0.167		617	34.08	
	7	300	3500	0.086		719	31.06	
	4	250	3000	0.083		617	30.98	
III	8	450	3500	0.129	11	432	39.69	
	9	350	3500	0.100		432	38.43	
	10	300	3000	0.100		370	38.43	
	7	300	3500	0.086		432	37.83	
IV	11	550	3000	0.183	22	740	31.27	
	12	600	3000	0.200		740	31.92	
	1	450	3500	0.129		863	29.31	
	10	300	3000	0.100		740	28.38	

Therefore, the method evaluation output of the various traffic flow of the case study proved that the method dynamically capable to select the best possible cycle pattern and to optimize the traffic parameters of movements and intersection.

Immediately, after changing the traffic condition and the traffic flow on intersection the method changed the cycle pattern and modified the cycle timing to be able to maintain or to hold the delay in the lowest possible.

TABLE X. SUMMARY OF CASE STUDY

	Cycle Time Sec	Average Delay Sec	Congestion Degree	Capacity of intersection Veh/hr
Case 1	90	32.24	0.821	10550
Case 2	75	26.65	0.745	10103
Case 3	90	33.73	0.811	9934

As shown in the summary of case study in Table X, the method selected the optimum cycle pattern; adjusted the timing of stop light to real-time traffic; and maximized the traffic parameter of intersection with cycle pattern and timing modification.

VI. CONCLUSION

This study provides the dynamic method for signalized intersection under saturation flow (uncongested) traffic to minimize the delay, to avoid traffic conflicts and to increase the capacity of intersection in more efficient and innovative approach of optimizing the cycle time for intersections.

Currently, the existing traffic lights program are fix time; pre phase and pre cycle time which cannot be adjusted the cycle pattern and green time of phases on the real traffic flow and limited to optimize the cycle for different traffic flow.

Unlike to this method, it will cover all the intersection based on the number of leg of intersection including all the movements with any geometric characteristics.

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