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Intelligent Transport Systems (ITS)
Preliminary Communication
Submitted: Jan. 23, 2015
Accepted: Oct. 10, 2015

OPTIMIZATION OF SIGNAL TIMING OF INTERSECTIONS BY INTERNAL METERING OF QUEUE TIME RATIO OF VEHICLES IN NETWORK SCALE

ABSTRACT

Optimization of signal timing in urban network is usually done by minimizing the delay times or queue lengths. Sincethe effect of each intersection on the whole network is not considered in the mentioned methods, traffic congestion may occur in network links. Therefore, this paper has aimed to provide a timing optimization algorithm for traffic signals using internal timing policy based on balancing queue time ratio of vehicles in network links. In the proposed algorithm, the difference between the real queue time ratio and the optimum one for each link of intersection was minimized. To evaluate the efficiency of the proposed algorithm on traffic performance, the proposed algorithm was applied in a hypothetical network. By comparing the simulating software outputs, before and after implementing the algorithm, it was concluded that the queue time ratio algorithm has improved the traffic parameters by increasing the flow as well as reducing the delay time and density of the network.

KEY WORDS

internal metering; network traffic; queue time ratio; traffic signals; coordination;

1. INTRODUCTION

Signalized intersections are controlled by both separate and coordinated methods. Separate control method refers to the condition in which each intersection is controlled only based on the measured parameters of that intersection without considering the performance of adjacent intersections. Coordinated control method considers the effect of adjacent intersections. Maximum efficiency of network traffic flow leads to the best type of phasing, timing and optimized cycle length for each intersection. It can be also obtained from interaction of intersections between each other. Consequently, using coordinated control has been considered.

In under-saturated conditions, minimizing the delay and stop, and maximizing bandwidth are the applied criteria. However, these criteria do not have the required efficiency in over-saturated conditions because traffic suffers from queue spillback in the intersecting (feeder) routes; so, formulations based on new efficiency criteria are needed for maintaining traffic optimization qualifications in the over-saturated condition so that queue management stages are also included.

Rathi (1991) widely classified control strategies into two categories of internal and external. Internal control is a controlling strategy that is applied in a controlled region while external control limits traffic volume that can enter the controlled region [1]. In a study, Derek (1992) investigated different control and queue management strategies in urban network at peak time and proposed two methods of: (1) gate management (2) determining intersection timing difference during the peak traffic period. Rathi and Lieberman (1992) stated that inflow to highly congested sections can be managed in order to guide and control network traffic. Derek also divided network control into two subsets: (1) internal control and metering, (2) external control and metering [2].

Timing optimization algorithm of levelled signalized intersections in arterials uses internal metering policies (RT/IMPOST) for over-saturated arterials which was proposed by Lieberman et al. (2000) in order to fulfil the following objectives:

- Maximizing system performance through inhibiting two factors: (1) queue spillback that leads to blocking intersections and wasting green time, and (2) inhibiting "traffic shortage" that leads to input traffic delay on the stop line. Queue formation control is necessary for improving the exploitation all over the stop lines.
- Full use of storage capacity which is done followed by metering congestion conditions in a region and by managing queue formation with the concept of feed forward system. Providing equal services and allocating services to traffic of cross street and left turners; all travellers are serviced adequately and the imperative of traffic safety is observed [3].

Forughi et al. (2007) presented a method for urban traffic control, the optimization of which was based on ant colonies. In their research, they introduced an urban traffic control system, in which ant colonies optimization was used as the main part. They also used a routing adaptive planner to investigate the performance of the system. They could optimize route traffic using this control system [4].

Ghods and RahimiKian (2010) solved the problem of instant control of traffic flow in the freeway network by coordinating and integrating traffic controllers. They used the games theory to solve the mentioned problem. They also studied and tested the efficiency of their proposed method for controlling ramp and metering speed variable [5]. Chan get al. (2000) proposed an algorithm for estimating the queue length. The algorithm was used for instant control of traffic signals and only required one detector behind the stop line. This algorithm was also designed for timing optimization of traffic signals using internal metering policy [6].

Gazis (1964) proposed a method for controlling two adjacent over-saturated intersections in which queue length limitations were not considered [7]. Kim and Messer (1993) proposed an optimization method for designing signals in saturated diamond intersections. Gal-Tzur (1993) proposed a volume control strategy for over-saturated urban networks [8]. Michalopoulos and Stephanopolos (2004) presented a two-phase timing method called Bang-Bang Control for intersection control which tried to find "optimal switchover point" during over-saturated period and changedthe required time for each phase in the approaches [9].

Traffic congestion in large-scale urban traffic is often formed separately from traffic congestion of distinct intersections. According to future characteristics of these intersections, Cheng Wei, et al. (2009) presented the concept of traffic bottleneck. They found that traffic congestion in urban network could lead to flow blockage and would disturb the flowing traffic which resembles the effect of Domino Game. Domino Effect in traffic usually occurs when expansion of local traffic is blocked. Improper design and timing of the route's traffic signals are the main reasons for creating the Domino Effect in traffic [10].

Azimirad et al. (2010) presented a novel model and a fuzzy logic controller for an isolated signalized intersection to optimally control traffic flows under both normal and exceptional traffic conditions. The object of the model is minimizing the waiting time and the length of queue. State-space equations were applied to formulate the average waiting time of vehicles in traffic network at fixed time control [11].

Zhang and Wang (2011) proposed a stochastic model to dynamically optimize the minimum and maximum green times for traffic actuated control at isolated intersections. They used real-time queue lengths and traffic arrival characteristics for each phase [12]. Lo et al. (2001) developed a dynamic traffic control system named Dynamic Intersection Signal Control Optimization (DISCO). DISCO considers the entire Fundamental Diagram of the traffic flow and works with time-variant traffic patterns and derives dynamic adaptive timing plans [13].

Geroliminis and Skabardonis (2011) accomplished a methodology to identify queue spillovers in urban networks with signalized intersections. They used data such as counts and occupancy from loop detectors [14]. Hadad et al. (2010) conducted a study on an isolated controlled vehicular traffic intersection with two movements. They proposed a discrete-event max-plus model to formulate an optimization problem for the green-red switching sequence [15].

To date, there has not been any appropriate internal metering algorithm based on the queue time of vehicles in the network, which can be used in different conditions of traffic congestion. By using such an algorithm, it is possible to apply regional traffic management policies and prevent over-saturated conditions. The objective of this research was to provide an algorithm for controlling the network traffic by coordinating signals in intersections and to implement the algorithm on simulating software in order to manage traffic and avoid congestion and disturbance in the network.

The considered algorithm can be turned into a functional algorithm for simulating software. The research was performed based on hypothetical information and in a theoretical way. Coordination of traffic signals in the network was obtained by mathematical formulations and their analyses and then the results were entered into the software as green times of signals. In this study, traffic was controlled using link queue time ratio. Link queue time ratio is equal to the movement time ratio of vehicles in free conditions to congested conditions. This ratio must be placed between maximum and minimum volumes in order to cause queued discharge at appropriate time and prevent more-than-expected delays.

2. METHODOLOGY

2.1 Algorithm structure

As mentioned before, Lieberman et al. provided an algorithm for controlling queue spillback in arterials by limiting queue length ratio which was defined as the ratio of the queue length to the route length [16]. It has to be considered that controlling delay time as a prominent traffic parameter can optimize network traffic remarkably. Consequently, this study proposes the queue time ratio which has direct effect on the delay time. Queue time ratio means movement time ratio of vehicles in free flow conditions to congested flow.

New relations are obtained for controlling delay time in the network level. In order to limit the queue time ratio, Lieberman et al.'s algorithm should be revised. These changes are: (1) converting queue length ratio to queue time ratio, and (2) generalizing the constraints related to offset level and queue time ratio of the network. In the modified algorithm, all the adjacent intersections are considered for calculating green time of each intersection. In other words, Lieberman et al.'s research was based on the length and was proposed for a single arterial. However, the base of this study is time and is extended for a network. *Figure 1* shows traffic relationship of adjacent intersections.

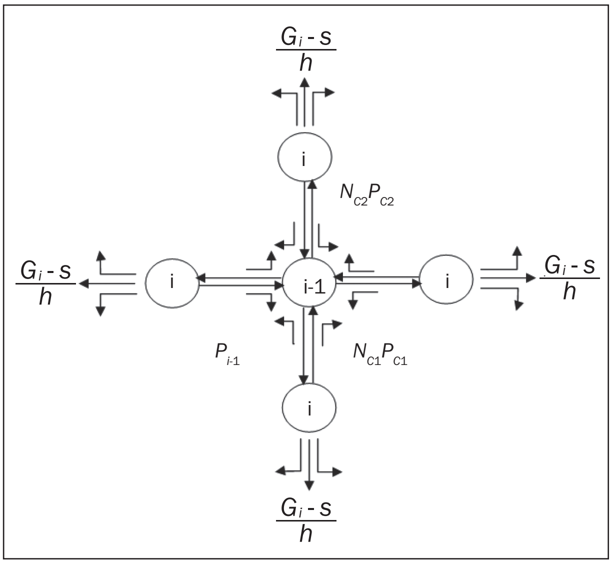

Figure 1 – The relationship of adjacent intersections

The queue time ratio algorithm is based on the balance in times of queues that are related to successive cycles. The detailed explanation of the algorithm steps is presented below. It should be considered that the mentioned equations in this explanation are depicted in part 2.2.

First, the initial value of green time (G) for each intersection is estimated by using *Equation 1* and its value is controlled based on the assumed minimum and maximum accepted values.

Second, for each arterial the queue time ratio ($m_{0,i,j}$) should be estimated, which is the sum of the proportion of vehicles' travel time in free flow to congested flow ($\frac{T_0}{T}$) and queue time ratio gradient (Δm_0). This parameter ($m_{0,i,j}$) should be limited to the minimum and maximum values which are presented in *Equations 2* and *3*, respectively. It should be considered that Δm_0 depends on G. Consequently, if the estimated G supports the suggested constraints for $m_{0,i,j}$, the initial reached green time will be accepted; if not, it should be revised. Then, the accepted green time is used for simulations in the next section.

Third, intersection time differences (Δ) have to be calculated and limited by their minimum and maximum values, which can be obtained by *Equation 4*. It has to be mentioned that the target function of the algorithm is estimating the optimum queue time ratio by minimizing its difference with the current queue time ratios. These parameters are presented in *Equation 4*.

2.2 Algorithm formulation

The mentioned equations are the relations of traffic network control which were obtained by modifying the available relations for arterials [16]. These adjustments in the duration of signal must meet systematic traffic control requirements because phase duration in an intersection depends on its adjacent intersections. It has to be mentioned that Lieberman et al. estimated green time of the downstream intersection based on maintaining stable queue assumption in an arterial. In this study, this assumption is utilized for entire adjacent intersections by involving all their characteristics in the equation.

According to *Equation 1*, which is adopted from Lieberman et al. [16], cycle length, proportion of total traffic on the cross street approaches, percent of turners from downstream intersection, percent of saturation on cross street and number of lanes for all adjacent intersections are used to calculate the green time of downstream intersection.

$$G_{i-1} = \frac{G_i - P_{i-1}s - x_{C1}(C-s)P_{C1}\frac{(LN)_{C1}}{(LN)_i} - x_{C2}(C-s)P_{C2}\frac{(LN)_{C2}}{(LN)_i}}{1 - P_{i-1} - X_{C1}P_{C1}\frac{(LN)_{C1}}{(LN)_i} - X_{C2}P_{C2}\frac{(LN)_{C2}}{(LN)_i}} \quad (1)$$

G_{i-1} - Green time servicing the feeder arterial approach, sec.

G_i - Green time servicing the subject arterial approach, sec.

P_{i-1} - Percent of turners from arterial feeder approach

$X_{C1,C2}$ - Percent of saturation on cross street 1 and 2
C - Cycle length, sec.
s - Lost time per green phase, sec.
$P_{C1,C2}$ - Proportion of total traffic on the cross street approaches 1 and 2, respectively, that turns onto arterial link.
$(LN)_{C1,C2}$ - Number of lanes on the cross street approaches 1, 2, respectively
LN_i - Number of lanes in intersection i.

Typically, it is not possible to provide system constraints for adjusting all phase durations of signals; therefore, queue time in all saturated approaches is adjusted at its optimal values [16].

For reaching the algorithm which controls delay time of network, the proportion of average length of vehicles in queue to the length of link has to be converted to the proportion of the average delay time of vehicle in queue to the travel time of vehicle in free condition, $\frac{T_V}{T_0}$. This change is the base of the queue time ratio algorithm in this study.

The minimum travel time ratio in free flow condition to congested flow one $[m_0]_{\min}$, which is formed by the incoming traffic from cross street for the upstream intersection, is presented in *Equation 2*. Relative to the mean time wasted by the vehicle in the queue, this value depends on vehicles' movement time in congested conditions, which is the mean of delay time.

$$[m_0]_{\min} = \max\left[\frac{T_V}{T_0} N_C P_C \frac{(LN)_C}{(LN)_i}, \frac{2T_V}{T_0}\right] \quad (2)$$

where

$[m_{0,i,j}]_{\min}$ - Minimum queue time ratio in intersection i and approach j
T_V - Average lost time in queues, assumed the proportion of delay to number of vehicles in the links;
T_0 - Vehicle travel time in free situations;
P_C - Proportion of total traffic on the cross street approaches, that turns onto arterial link.;
$(LN)_C$ - Number of lanes on the cross street approaches;
LN_i - Number of lanes in intersection i.
LN_c - Number of vehicles on the cross street approaches, that turns onto arterial link.

The maximum ratio of travel time in free flow condition to congested flow one $[m_0]_{\max}$, which is calculated in each stage to avoid the increasing movement time expressed in *Equation 3*:

$$[m_0]_{\max} = \min\left[1 - \frac{W+F}{L}, 1.1\frac{(G_i - s)T_V}{hT_0}, 1.1\frac{L_D}{L}\right] \quad (3)$$

$[m_{0,i,j}]_{\max}$ - Maximum queue time ratio in intersection i and approach j;
W - Width of upstream intersection of subject approach;
F - Safety factor to guard against spill-back;
L - Arterial approach length;
G_i - Green time servicing the subject arterial approach, sec;
s - Lost time per green phase, sec;
T_V - Average lost time in queues, assumed the proportion of delay to number of vehicles in the links;
h - Mean queue discharge headway, sec/veh.;
T_0 - Vehicles travel time in free situations;
L_D - Distance between detector and stop-bar.

The following targetfunction, explained in *Equation 4*, tries to adjust the phase duration in a state so that the differences in ratios of queue times will be minimized from their optimum values; i.e. target function is based on minimizing the created time queue ratio in the network with its optimum value.

By solving this target function, green time of downstream intersection can be reached. To solve the function the initial value of green time (G) for each intersection is estimated by using *Equation 1* and its value is controlled based on the assumed minimum and maximum accepted values. Then, if the suggested constraints are supported the initial reached green time will be accepted; if not, the value of G has to be changed. The accepted green time is imported in simulation software.

$$Minimize = \sum_{i,j}(m_{0,i,j} - \hat{m}_{0,ij})^2 + \sum_{i,j}(\bar{m}_{0,i,j} - \hat{\bar{m}}_{0,i,j})^2 \quad (4)$$

S.T:

$$m_{0,i,j} = \frac{T_0}{T} + \Delta m_0$$

$$\tau = \lfloor (Ln)_{i-1}^{C1} X_{C1} P_{C1} S^{C1} + (LN)_{i-1}^{C2} X_{C2} P_{C2} S^{C2} \rfloor (C - G_{i-1} - S)$$

Let:

$$Ri = \frac{(LN)_{i-1}^j}{(LN)_i^j},$$

then

$$\Delta m_0 = (G_{i-1} - s)\left\{R_i S^j (1 - P_i^l + P_i^l P_{i-1})\frac{T_V}{T_0}\right\} - G_i S^j \frac{T_V}{T_0}$$
$$-(G_{i-1} - s)\left\{R_i S^j P_{i-1})\frac{T_V}{T_0}\right\} + \frac{\tau}{(LN)_i^j}\frac{T_V}{T_0} + sS^j\frac{T_V}{T_0}$$

$$m_{0,i,j} \geq \lfloor m_{0,i,j} \rfloor_{\min} \qquad m_{0,i,j} \leq \lfloor m_{0,i,j} \rfloor_{\max}$$

$$\lfloor \Delta_{0,i,j} \rfloor_{min} \leq \Delta_{i,j} = T_0 \left[\frac{1 - m_{0,i,j}}{v_1} - \frac{m_{0,i,j}}{w} + \lfloor m_{0,i,j} \rfloor_{max} \left(\frac{1}{w} - \frac{1}{u} \right) \right] \leq \lfloor \Delta_{0,i,j} \rfloor_{max}$$

$$\lfloor \Delta_{0,i,j} \rfloor_{max} = \frac{T_0}{v_1} \left[1 - m_{0,i,j} \left(1 + \frac{v_1}{w} \right) \right] + \min \left[\frac{G_i - s}{1 - P_{i-1}}, \frac{L - W}{w} \right] \left(1 - \frac{w}{u} \right)$$

$$\lfloor \Delta_{0,i,j} \rfloor_{min} = \frac{T_0}{v_1} \left[1 - \frac{m_{0,i,j} h v_l}{T_v} \right]$$

$$\lfloor G_{i-1,j} \rfloor_{min} \leq G_{i-1,j} \leq \lfloor G_{i-1,j} \rfloor_{max}$$

$$\lfloor G_{i-1,j} \rfloor_{min} = 15\,\text{sec} \qquad \lfloor G_{i-1,j} \rfloor_{max} = 120\,\text{sec}$$

$m_{0,i,j}$ - Queue time ratio in intersection *i* and approach *j*, outbound, assumed the proportion of the vehicles travel time in free situations to congested situations;

$\hat{m}_{0,i,j}$ - Optimum queue time ratio in intersection *i* and approach *j*, outbound;

$\bar{m}_{0,i,j}$ - Queue time ratio in intersection *i* and approach *j*, inbound, assumed the proportion of the vehicles travel time in free situations to congested situations;

$\hat{\bar{m}}_{0,i,j}$ - Optimum queue time ratio in intersection *i* and approach *j*, inbound;

T_0 - Vehicles travel time in free situations;

T - Vehicles travel time in congested situations, assumed as delay;

Δm_0 - Change in queue time ratio;

$(LN)_i^j$ - Number of lanes in intersection *i* and approach *j*.

$(LN)_{i-1}^j$ - Number of lanes in intersection *i*-1 and approach *j*.

$X_{C1,C2}$ - Percent saturation on cross street 1 and 2;

$P_{C1,C2}$ - Proportion of total traffic on the cross street approaches 1 and 2, respectively, that turns onto arterial link.

S^j - Average vehicle discharge rate, veh/sec.

C - Cycle length, sec.

G_{i-1} - Green time servicing the feeder arterial approach, sec;

G_i - Green time servicing the subject arterial approach, sec;

s - Lost time per green phase, sec;

P_{i-1} - Percent of turners from arterial feeder approach;

P_i^l - Percent of left-turners from arterial subject approach;

$(LN)_{C1,C2}$ - Number of lanes on the cross street approaches 1, 2, respectively;

$\lfloor m_{0,i,j} \rfloor_{min}$ - Minimum queue time ratio in intersection *i* and approach *j*;

$\lfloor m_{0,i,j} \rfloor_{max}$ - Maximum queue time ratio in intersection *i* and approach *j*;

Δ - Approach signal offset;

Δ_{min} - Minimum signal offset;

Δ_{max} - Maximum signal offset;

v_1 - Mean speed of the lead vehicle of the incoming platoon, assumed 6 m/sec;

u - Discharge wave speed, assumed 10 m/sec;

w - Shock wave speed, assumed 8 m/sec;

L - Arterial approach length;

W - Width of upstream intersection of subject approach;

T_V - Average lost time in queues, assumed the proportion of delay to the number of vehicles in the links;

v_l - Mean speed of the lead vehicle of the incoming platoon travelling without stopping;

$\lfloor G_{i-1,j} \rfloor_{min}$ - Minimum accepted green time servicing the feeder arterial approach, sec;

$\lfloor G_{i-1,j} \rfloor_{max}$ - Maximum accepted green time servicing the feeder arterial approach, sec.

2.3 Preliminary simulation

To investigate the performance of time queue ratio algorithm in saturated, over-saturated and under-saturated networks, the results of implementing a traffic network should be compared before and after implementing the algorithm. In this paper, a hypothetical network in Aimsun® simulating software was used, as presented in *Figure 2*. This network had nine intersections. The signals were controlled in an actuated way, which were consistent with the parameters of actuated system in intersections of the city of Tehran. The intersections mostly had three phases and their maximum cycle length varied from 160 to 200 sec. Origin-destination matrix and phasing type for the hypothetical network were considered based on the general scheme of central intersections in the city of Tehran. *Table 1* presents the origin-destination matrix.

The studied network is presented in *Figure 2*. All the links have similar properties including similar number of lanes and passage classification. The network was loaded under three input loads: initial input volume,

Table 1 – Origin-destination matrix at peak hours in terms of vehicle per hour

Centroid	1a	3b	9a	8b	7b	6a	2a	1b	sum
1a	-	200	800	500	200	500	50	-	2,250
2b	-	50	500	500	200	20	50	-	1,320
3b	50	-	100	500	800	-	200	100	1,750
9a	500	100	-	-	50	100	500	500	1,750
8b	300	500	500	-	50	200	500	200	2,250
7b	50	300	500	-	-	50	50	50	1,000
6a	500	-	200	50	100	-	200	200	1,250
1b	-	100	500	200	100	100	-	-	1,000
sum	1,400	1,250	3,100	1,750	1,500	970	1,550	1,050	12,570

20% increase of initial volume and 20% decrease in initial volume.

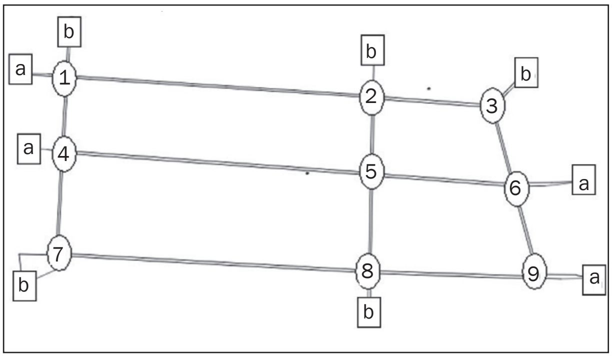

Figure 2 – Number of intersections in the hypothetical network

The network loading is performed using origin-destination matrix in order to simulate the above-mentioned network in the software. Traffic signals are determined in an actuated way. Aimsun simulating software is used to optimize the time of signals. After running the network, all the results and parameters will be extracted.

2.4 Solving the optimization algorithm

Considering the output of parameters in the previous stage, the algorithm solution will begin. These parameters include speed, queue length, percentage of turners, flow, density, delay, stop and travel times. Also, value of a number of parameters is determined considering the network, which includes downstream cycle length, distance of detector from intersection, flow of vehicles on the main and cross routes and the number of lanes on the main and cross routes. Using the mentioned parameters, target function and constraints of time queue ratio algorithm are defined in the solver section of Excel(TM) software. This software is selected because of its ability to define the limitations in formulas. After defining the target function and constraints in the solver section, optimization type and algorithm solution trend are determined.

Then, green time duration and optimal cycle length are obtained for each phase in each intersection by solving the mentioned algorithm. Solving the algorithm will continue until finding an optimal solution. When an optimal solution is found for the target function, green time duration will be registered for the intersection in order to be applied to the network in re-simulation. *Table 2* presents the length of optimal cycles for each intersection.

As shown in *Table 2*, the value of cycle length for over-saturated state was less than other traffic conditions because the algorithm provided more constraints

Table 2 – Optimal cycle length for each intersection

Intersection	Without applying algorithm	After applying algorithm		
		Under- Saturated	Saturated	Over- Saturated
1	200	200	200	120
2	190	155	120	194
3	180	105	105	105
4	160	95	96	85
5	200	150	200	150
6	200	191	86	86
7	180	156	146	146
8	200	198	147	198
9	200	160	200	160

for the network in over-saturated conditions to prevent blocking and congestion of streets.

2.5 Re-simulation

The calculated optimal green times and cycle lengths related to each phase will be entered into the similar software as input and five sec. is added to the obtained time as maximum green time. To use this algorithm in Aimsun software, four 15-min.time intervals should be determined for one peak hour. The algorithm is solved for each of these intervals and the obtained green times of each interval are entered into the similar software.

As noted above, this process is performed with three different input volumes. Changing the primary volume is done in origin-destination matrix. So, performance of queue time ratio algorithm is studied in saturated, over-saturated and under-saturated conditions. The simulating software is run with input green times and the results are compared with the state without algorithm implementation in order to identify the effect of using queue time ratio algorithm on the traffic network.

3. RESULTS AND DISCUSSION

Some tables and diagrams are presented in this section, which represent the state of the studied network after implementing queue time ratio algorithm and compare network state with the before-implementation state. *Table 3* shows software output parameters before and after implementing the queue time ratio algorithm. The software is run for one hour.

Considering *Table 3*, it is clear that running the algorithm in the network in under-saturated conditionresults41% delay reduction, 39% density reduction, 2% flow increase and 46% speed increase. At the same time, running the algorithm in saturated condition results in 45% delay reduction, 53% density reduction, 30% flow increase and 53% speed increase. Under over-saturated condition, the changes are 25% delay reduction, 23% density reduction, 18% flow increase, and 32% speed increase. Changes of the mentioned parameters are shown in *Figures 3, 4* and *5* for under-saturated, saturated and over-saturated traffic conditions, respectively.

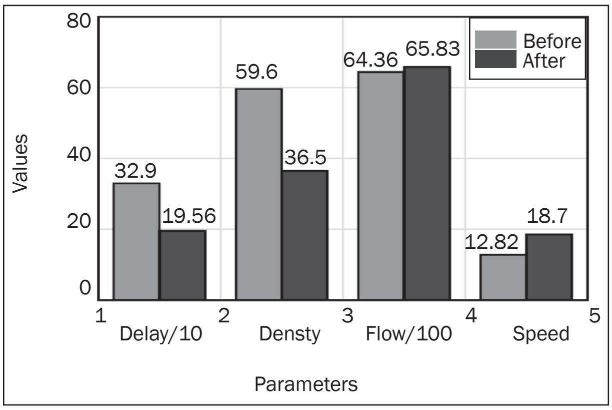

Figure 3 – Parameter changes before and after implementing queue time ratio algorithm in under-saturated traffic condition

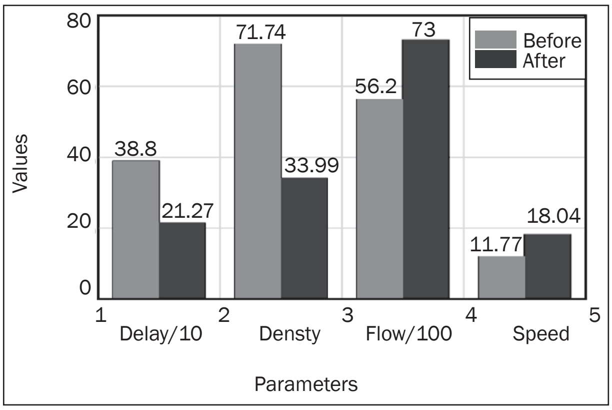

Figure 4 – Parameter changes before and after running queue time ratio algorithm in saturated traffic condition

Table 3 – Results of virtual network simulation in Aimsun software before and after implementing the queue time ratio constraint

Parameters	Unit	Under- Saturated		Statured		Over- Saturated	
		before	after	before	after	before	after
Delay time	second/km	329	195.6	388	212.7	484.5	361.5
Density	veh/km	59.6	36.5	71.74	33.99	72.1	55.58
Flow	veh/h	6,436	6,583	5,620	7,300	5,243	6,170
Speed	km/h	12.82	18.7	11.77	18.04	10.23	13.5
Stop time	second/km	305.6	175.4	364	190.9	459.6	337.8
Stoppages	#/veh/km	4.21	3.62	4.44	3.92	4.63	5.4
Total travel distances	km	9,455	9,391	8,058	10,642.1	7,422.7	8,839.3
Total travel times	hours	1,000	662	966	779.5	1,069.5	998.1
Travel time	second/km	394	260.5	453	277.5	549.4	426.4

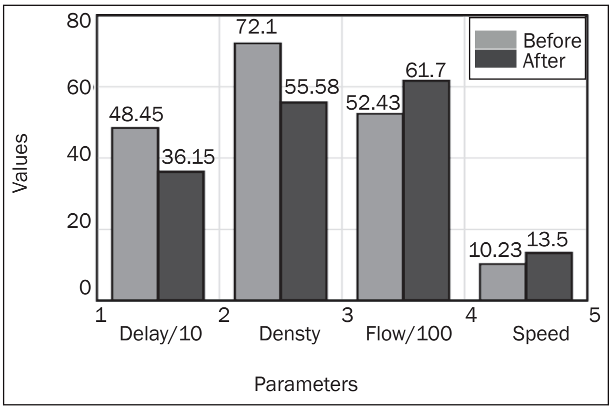

Figure 5 – Parameter changes before and after i mplementing queue time ratio algorithm in over-saturated traffic condition

In the simulating software (Aimsun), the maximum green time value is changed to about five sec more than the value obtained from the target function. For queue time ratio algorithm, queue ratio is calculated in each route and then the results are compared with before-implementation algorithm. The application of constraints in queue time ratio in the whole network reduces the queue length ratio. The amount of this reduction is different in under-saturated, saturated and over-saturated conditions. In under-saturated, saturated and over-saturated traffic conditions, queue length ratios decrease by about 37%, 51% and 27%, respectively. As shown by the results, the queue time ratio algorithm decreases the queue length in the network in each of the three traffic conditions. *Figures 6, 7* and *8* schematically show the queue length and traffic congestion for under-saturated, saturated and over-saturated traffic conditions, respectively, in order to present a comparison for the changes of queue length ratio in each of the network routes.

4. CONCLUSION

In this study, new relations were obtained to control traffic congestion in the network. These relations are gained by modifying the algorithm which has been already presented for controlling the queue length ratio in an arterial. Then, the queue length ratio algorithm is changed to queue time ratio algorithm which is applied for creating the balance in times of queues in a network. The modified algorithm optimizes traffic signals timing using internal metering policy. In the algorithm, all the adjacent intersections are considered for calculating green time of each intersection. As result, the discharge time of vehicles from the intersection is acceptably maintained and excessive delays are prevented.

In the proposed algorithm, the queue time ratio of the link means movement ratio of vehicles in free conditions to congested conditions; i.e. delay. To obtain this algorithm, first, queue time ratio constraints of each route and green time duration of intersections are presented. Then, the studied target function and its constraints are mentioned.

Queue time ratio algorithm on the traffic network is provided with different inputs: (1) applying primary flow which results in saturated traffic conditions; (2)

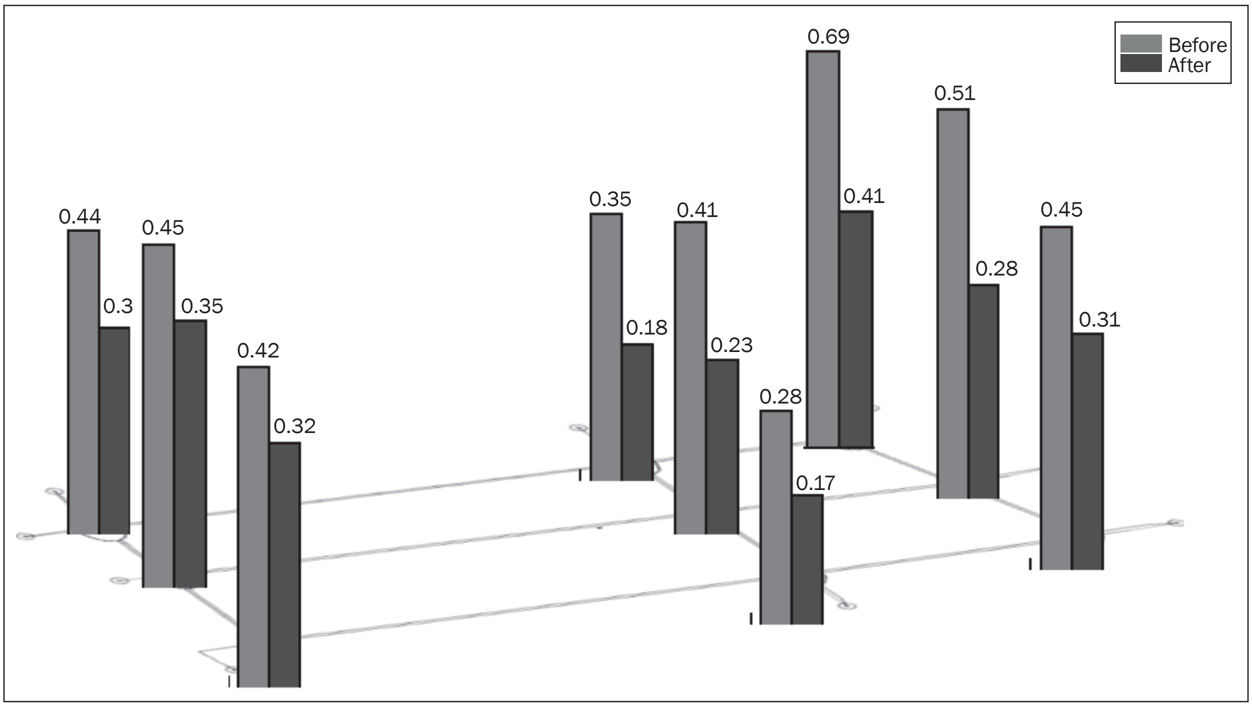

Figure 6 – Comparing queue length ratio with and without considering queue time ratio algorithm for under-saturated condition

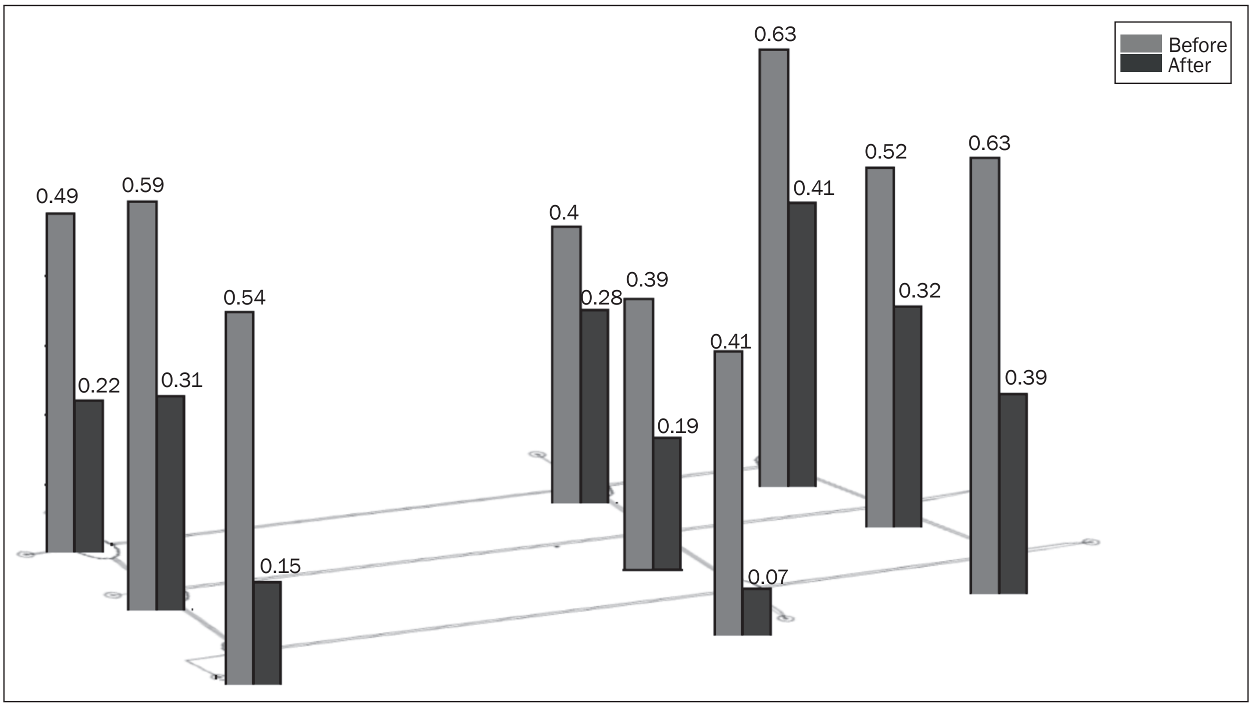

Figure 7 – Comparing queue length with and without considering queue time ratio algorithm for saturated condition

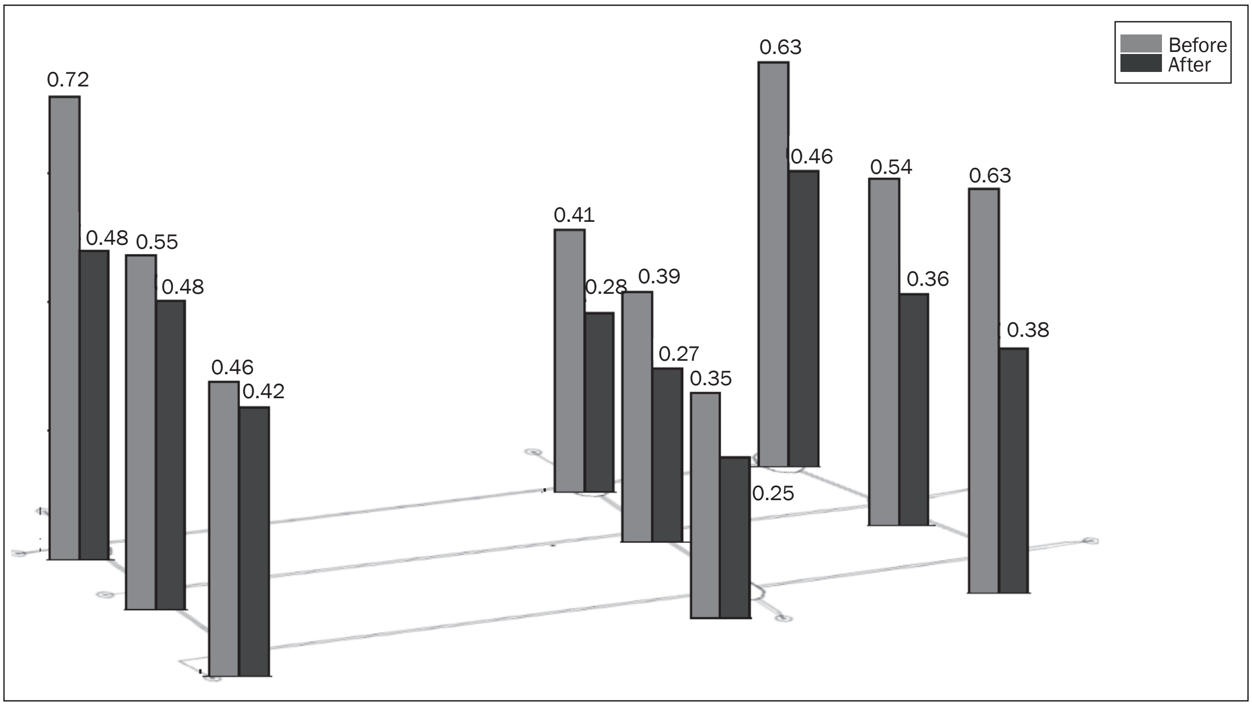

Figure 8 – Comparing queue length with and without considering queue time ratio algorithm for over-saturated condition

20% increase in inflow, which leads to over-saturated network; and (3) 20% decrease in inflow, which provides under-saturated conditions for the network.

Considering the obtained results, this algorithm has equal effect on saturated, over-saturated and under-saturated networks, which leads to increased inflow and speed and considerably decreases the delay, density and queue length ratio in the entire network.

The set of results obtained from implementing queue time ratio algorithm shows that application of internal metering policy in street network can prevent developing queues on the routes. Accordingly, traffic congestion is prevented in the network, both locally and generally.

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بهینه سازی زمانبندی چراغ های راهنمایی در تقاطعات از طریق محدودسازی نسبت زمان صف وسایل نقلیه در سطح شبکه

چکیده

معمولاً بهینه‌سازی زمانبندی چراغهای راهنمایی در شبکه معابر به روش حداقل کردن تأخیر و یا طول صف صورت می‌گیرد. چون در این روشها تأثیر هر تقاطع بر کل شبکه در نظر گرفته نمی‌شود ممکن است در پیوندهایی از شبکه تراکم ترافیک رخ دهد. بنابراین هدف از این مقاله ارائه یک الگوریتم بهینه‌سازی زمانبندی چراغ-های راهنمایی با استفاده از سیاست زمانبندی داخلی،بر اساس متعادل سازی نسبت زمان صف وسایل نقلیه در پیوندهای شبکه بوده است. در الگوریتم پیشنهادی اختلاف نسبت زمان صف وسایل نقلیه با مقدار بهینه‌ی آن در هر پیوند منتهی به تقاطع حداقل شده و بر اساس آن زمانبندی بهینه برای تقاطعها بدست می آید. به منظور بررسی تأثیر الگوریتم پیشنهادی بر روی عملکرد ترافیک یک شبکه تحت بار فرضي با استفاده از نرم افزار شبیه سازي شده است. با مقایسه خروجي‌هاي نرم-افزار شبیه‌ساز در دو حالت قیل و بعد از اعمال الگوریتم پیشنهادي، مشخص شد که الگوریتم نسبت زمان صف شاخص های ترافیکی شبکه را از طربق افزایش حجم عبور جریان ترافیک، و همچنین کاهش زمان تأخیر و چگالی به مقدار قابل ملاحظه ای بهبود داده است.

کلمات کلیدی
محدودسازی درونی، ترافیک شبکه، نسبت زمان صف، چراغهای راهنمایی، هماهنگسازی

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