International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 7 Ver V || July 2018 || PP 48-58

Real Time Traffic Control to Optimize Waiting Time of Vehicles at Road Arterial Networks

Yogeswary Raviraj[1], W.B.Daundasekera[2]
[1]*(Department of Mathematical Sciences, Faculty of Applied Sciences, South Eastern University of Sri Lanka, Sri Lanka)*
[2]*(Department of Mathematics, Faculty of Science, University of Peradeniya, Sri Lanka)*
Corresponding Author: Yogeswary Raviraj

Abstract: *This paper presents a real time nonlinear quadratic programming model to minimize the aggregate delay time of vehicles at each intersection by minimizing the total number of vehicles at each intersection at the signalized two intersections arterial. This can be extended to more than two intersections arterial network by expanding the groups which is explained in this paper. The most important efficiency and simply getting factor of traffic signal control is the number of vehicles in a queue at the lanes of intersections. The initial number of vehicles at each lane at the intersections is counted by a camera which is the most exact method among other existing methods.The model is developed to minimize the number of waiting vehicles from cycle to cycle. This proposed model includes inter green signal time which is one of the main aspect compared to other existing models proposed in the former research. This model also includes restrictions for upper bound for green signal time and cycle time allocation which leads to exact and appropriate allocation for green signal time. Non- zero and positive queue lengths at lanes are maintained under special condition for oversaturation case. The proposed model is solved by the method of sequential quadratic programming coded in MATLAB environment.*
Keyword: *aggregate delay time, nonlinear sequential quadratic programming, optimization, real time, signalized arterial network*

Date of Submission: 10-07-2018 Date of acceptance: 24-07-2018

I. INTRODUCTION

Nowadays a tremendous increase in traffic in major cities is a very serious problem. This has resulted in increasing travel time, traffic congestion, gas emissions, and fuel consumption [1]. Intersections are the bottlenecks of the transportation networks on roads, and time spent waiting at intersections tends to account for 20%− 50% of total travel time within cities [2]. Many methods had been implemented to overcome this problem such as broadening intersection approach, canalization, adding left turning lane and optimization of intersection signal parameters. Among this methods, very effective method is optimization of intersection signal parameters such as cycle time, green split, phase sequence and offsets. Many optimization methods are available such as SUN et al [3] proposed an optimization model of the signal timing, based on supersaturated signal intersection. CHANG and LIN [4] proposed one disperse dynamic optimization model to solve the traffic flow supersaturated condition and used two-stage control system to produce optimal cycle and green splits.

Our objective of this research is to formulate a mathematical model to optimize phase sequence and minimize aggregate delay [5] time of vehicles and the total number of vehicles which are waiting at the signalized two intersections arterial network [6] due to red signal by allocating sufficient amount of green time for each signals and cycle time. This can be extended to more than two intersections arterial network by expanding the groups which is explained in this paper. To maintain the feasibility, the upper bound for cycle time and the upper bound for green signal time are limited. Special oversaturation condition is used to maintain non-zero and positive value for number of waiting vehicles at lanes. The real time data is calculated by using cameras [7] installed in every lane in the road intersections. This model is solved by sequential quadratic programming algorithm coded in MATLAB environment [8].

II. Methodology

In this research, we consider a signalized arterial road with two intersections namely Intersection 1 and Intersection 2 and eight lanes namely Lane *ij*, *i*=1, 2 and *j* = 1,2,3,4. We divide this arterial into four stages: in Stage 1, green signals (same amount of green signal time) will be on for Lane 12 and Lane 22 by grouping Lane 12 and Lane 22 ([Lane 12-Lane 22]), where the vehicles which are waiting at the Lane 12 and Lane 22 can go to each other three lanes through the intersection as shown in Stage 1 in the below Fig 1. Similarly, when the green signals are on for other two grouped lanes ([Lane 14-Lane 24], [Lane 11- Lane 21], [Lane 13-Lane 23]) the vehicles waiting in those lanes will proceed to different lanes as described in Stage 2, Stage 3 and Stage 4 in the Fig 1 below:

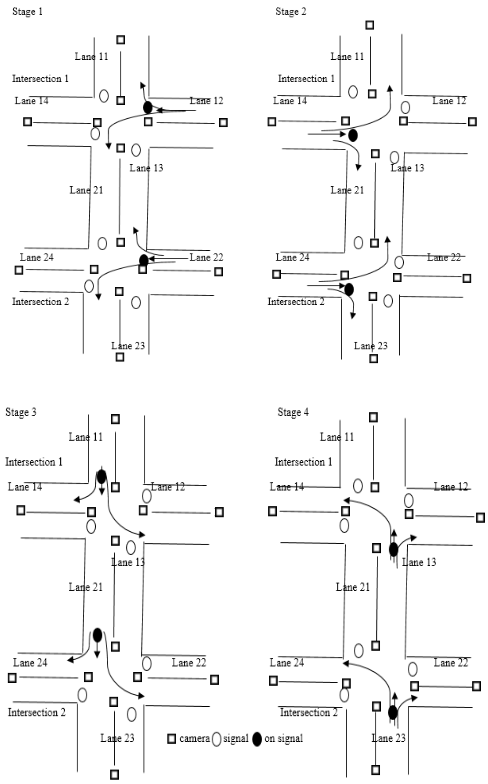

Fig 1. Green signals and stages (phases).

Each intersection makes its own plan with a difference of offset time. In this model the offset time for cycles is set to zero. Vehicles entering into the Lane 13 will be during green signal on for Lane 12, Lane 13 and Lane 14 only. Similarly, vehicles entering into the Lane 21 will be during green signal on for Lane 21, Lane 22 and Lane 24 only.

2.1 Formulation of the model:
2.1.1 Notations
Lane ij: j^{th} lane of i^{th} intersection at the arterial road i=1, 2, j=1, 2, 3, 4,
$N_{ij}(k)$: Number of vehicles in Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4 at cycle k,
$NT_i(k)$: Total number of vehicles at intersection i, i=1, 2, at cycle k,
Ig: inter green time, W_{ij}: Weighting parameter of Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4,
$g_{ij}(k)$: Allocated green time for the signal for Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4 at cycle k,
$f_{ij}(k)$: In coming flow rate of vehicles for the Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4 at cycle k,
$s_{ij}(k)$: Outgoing flow rate of vehicles for the Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4 at cycle k,
$S_{13}(k)$: Saturation flow rate of vehicles at Lane 13 at cycle k,
$S_{21}(k)$: Saturation flow rate of vehicles at Lane 21 at cycle k,
$e_{13}(k)$: Exit flow of vehicles at Lane 13 at cycle k, $\mathrm{e}_{21}(k)$: Exit flow of vehicles at Lane 21 at cycle k,
$d_{13}(k)$: Demand flow of vehicles at Lane 13 at cycle k, $\mathrm{d}_{21}(k)$: Demand flow of vehicles at Lane 21 at cycle k,
$(g_{ij}(k))_{\min}$: Minimum green time for the signal for Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4, at cycle k,
$(g_{ij}(k))_{\max}$: Maximum green time for the signal for Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4, at cycle k,
$C_i(k)$: Cycle time of intersection i, i=1, 2 at cycle k,
$(CT_i)_{\min}$: Minimum cycle time of i^{th} intersection i=1, 2, $(CT_i)_{\max}$: Maximum cycle time of i^{th} intersection i=1, 2,
$t_{1j}(k)$: Average vehicle turning rates at Intersection 1, $j = 1,2,4$, at cycle k,
$t_{2j}(k)$: Average vehicle turning rates at Intersection 2, $j = 2,3,4$, at cycle k,
$D_{ij}(k+1)$: Aggregate delay time of vehicles in cycle k at Lane j of i^{th} intersection i=1, 2, j=1, 2, 3, 4.
$DT_i(k+1)$: Aggregate delay time of vehicles in cycle k at Intersection i,,i=1, 2

2.1.2 Formulation

In Stage 1 Intersection 1, the aggregate delay time for (k+1)th cycle (i.e. aggregate delay time at the end of k^{th} cycle) is calculated by the aggregate delay time of vehicles in the Lane 12 during green signal is on and after the green signal is off which is represented by the shaded area of Stage 1 Intersection 1 in Fig 2.

In Stage 2 Intersection 1, the aggregate delay time for (k+1)th cycle (aggregate delay time at the end of k^{th} cycle) is calculated by the aggregate delay time of vehicles in the Lane 14 before green signal is on, during green signal is on and after the green signal is off which is represented by the shaded area of Stage 2 Intersection 1 in Fig 2. The other two stages can also be illustrated in a similar manner. The total delay time for (k+1)th cycle is illustrated in the figure below:

Intersection 1

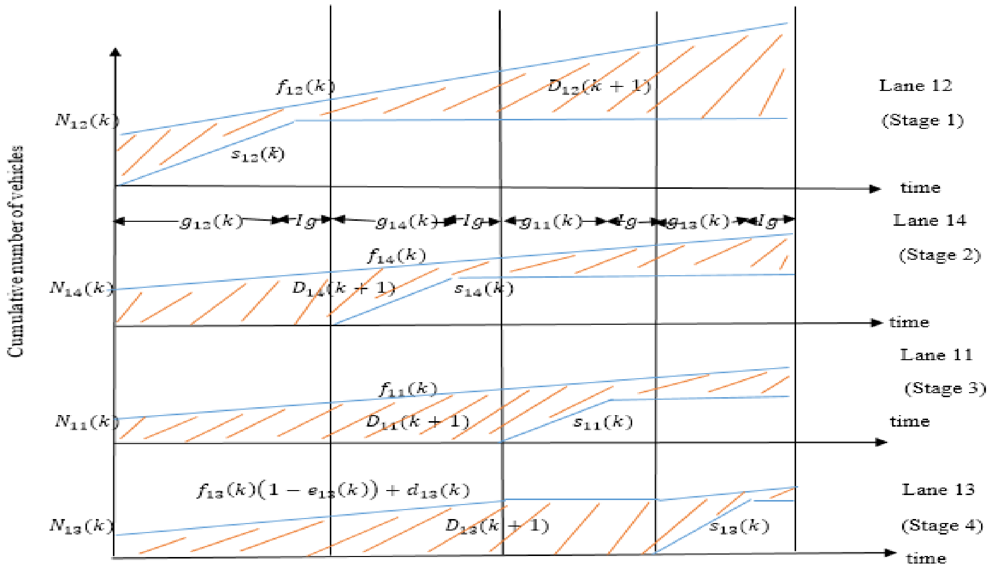

Fig 2. Number of vehicle and delay of four stages at Intersection 1

Aggregate delay time for vehicles at each stage at the end of cycle k is calculated from the area of the shaded region in the Fig 2 as given below:

$$D_{12}(k+1)=\frac{1}{2}\Big[2N_{12}(k)C_1(k)+f_{12}(k)C_1(k)^2-s_{12}(k)\big(g_{12}(k)\big)^2-2s_{12}(k)g_{12}(k)(4Ig+ g_{14}(k)+g_{11}(k)+g_{13}(k))\Big]\geq 0. \quad (1)$$

$$D_{14}(k+1)=\frac{1}{2}\Big[2N_{14}(k)C_1(k)+f_{14}(k)C_1(k)^2-s_{14}(k)\big(g_{14}(k)\big)^2-2s_{14}(k)g_{14}(k)(3Ig+ g_{11}(k)+g_{13}(k))\Big]\geq 0. \quad (2)$$

$$D_{11}(k+1)=\frac{1}{2}\Big[2N_{11}(k)C_1(k)+f_{11}(k)C_1(k)^2-s_{11}(k)\big(g_{11}(k)\big)^2-2s_{11}(k)g_{11}(k)(2Ig+ g_{13}(k))\Big]\geq 0. \quad (3)$$

$$D_{13}(k+1)=\frac{1}{2}\Big[2N_{13}(k)(g_{12}(k)+g_{14}(k)+2Ig)+[f_{13}(k)\big(1-e_{13}(k)\big)+d_{13}(k)](g_{12}(k)+g_{14}(k)+ 2Ig)^2+2[N_{13}(k)+(f_{13}(k)\big(1-e_{13}(k)\big)+d_{13}(k))(g_{12}(k)+g_{14}(k)+2Ig)](g_{11}(k)+Ig)+ 2[N_{13}(k)+(f_{13}(k)\big(1-e_{13}(k)\big)+d_{13}(k))(g_{12}(k)+g_{14}(k)+2Ig)](g_{13}(k)+Ig)+ [f_{13}(k)\big(1-e_{13}(k)\big)+d_{13}(k)](g_{13}(k)+Ig)^2-s_{13}(k)\big(g_{13}(k)\big)^2-2s_{13}(k)g_{13}(k)Ig\Big]\geq 0. \quad (4)$$

Here, $f_{13}(k)=t_{22}(k)s_{22}(k)+t_{23}(k)s_{23}(k)+t_{24}(k)s_{24}(k)$.

In Stage 1 Intersection 2, the aggregate delay time for (k+1)th cycle (i.e. aggregate delay time at the end of k^{th} cycle) is calculated by the aggregate delay time of vehicles in the Lane 22 during green signal is on and after the green signal is off which can be represented as the shaded area of Stage 1 Intersection 1 in Fig 3.

In Stage 2 Intersection 2, the aggregate delay time for (k+1)th cycle (aggregate delay time at the end of k^{th} cycle) is calculated by the aggregate delay time of vehicles in the Lane 24 before green signal is on, during green signal is on and after the green signal is off which can be represented as the shaded area of Stage 2 Intersection 1 in Fig 3. The other two stages can also be illustrated in a similar manner. The total delay time for (k+1)th cycle is illustrated in the figure below:

Intersection 2

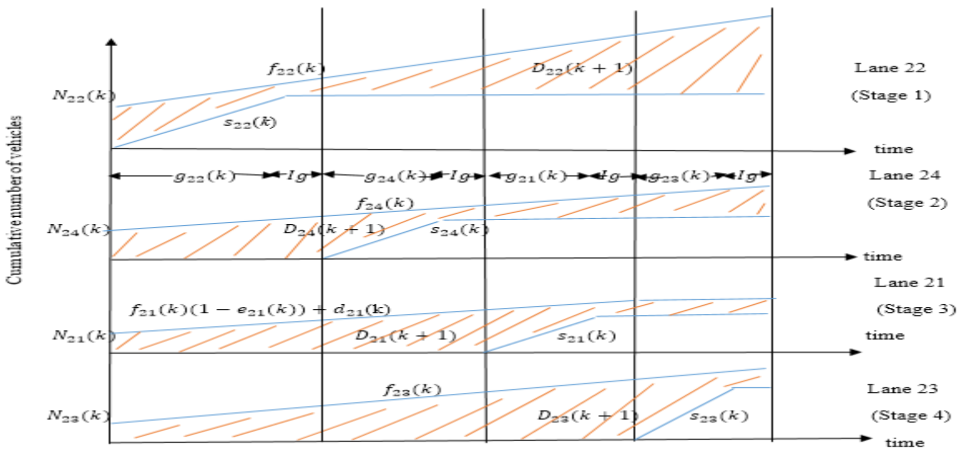

Fig 3. Number of vehicle and delay of four stages at Intersection 2

Aggregate delay time for vehicles at each stage at the end of cycle k is calculated from the area of the shaded region in the Fig 3 as given below:

$$D_{22}(k+1)=\frac{1}{2}\Big[2N_{22}(k)C_2(k)+f_{22}(k)C_2(k)^2-s_{22}(k)\big(g_{22}(k)\big)^2-2s_{22}(k)g_{22}(k)(4Ig+g_{24}(k)+g_{21}(k)+g_{23}(k))\Big]\geq 0. \tag{5}$$

$$D_{24}(k+1)=\frac{1}{2}\Big[2N_{24}(k)C_2(k)+f_{24}(k)C_2(k)^2-s_{24}(k)\big(g_{24}(k)\big)^2-2s_{24}(k)g_{24}(k)(3Ig+g_{21}(k)+g_{23}(k))\Big]\geq 0. \tag{6}$$

$$D_{21}(k+1)=\frac{1}{2}\Big[2N_{21}(k)(g_{22}(k)+g_{24}(k)+g_{21}(k)+3Ig)+[f_{21}(k)\big(1-e_{21}(k)\big)+d_{21}(k)](g_{22}(k)+g_{24}(k)+g_{21}(k)+3Ig)^2+2[N_{21}(k)+\big(f_{21}(k)\big(1-e_{21}(k)\big)+d_{21}\big)(g_{22}(k)+g_{24}(k)+g_{21}(k)+3Ig)](g_{23}(k)+Ig)-s_{21}(k)\big(g_{21}(k)\big)^2-2s_{21}(k)g_{21}(k)(2Ig+g_{23}(k))\Big]\geq 0. \tag{7}$$

Here, $f_{21}(k)=t_{11}(k)s_{11}(k)+t_{12}(k)s_{12}(k)+t_{14}(k)s_{14}(k)$.

$$D_{23}(k+1)=\frac{1}{2}\Big[2N_{23}(k)C_2(k)+f_{23}(k)C_2(k)^2-s_{23}(k)\big(g_{23}(k)\big)^2-2s_{23}(k)g_{23}(k)Ig\Big]\geq 0. \tag{8}$$

The number of vehicles in eight lanes at the end of the cycle k is given by the following eight equations. Equation 9 represents number of vehicles in Lane11 at the end of cycle k (or beginning of cycle k+1) which is equivalent to the total number of vehicles waiting at the beginning of cycle k (from camera readings), incoming number of vehicles into the Lane11 during green signal time, inter signal green time and red signal time and excluding outgoing number of vehicles during green signal time for the Lane 11. Similarly, the numbers of vehicles in Lane 12, Lane 14, Lane 22, Lane 23and Lane 24 at the end of cycle k (for cycle k+1) are given by the equations 10, 12, 14, 15 and 16 respectively. Equation 11 represents number of vehicles in Lane 13 at the end of cycle k (or beginning of cycle k+1) which is equivalent to the total of the number of vehicles waiting at the beginning of cycle k (from camera readings), incoming number of vehicles into the Lane 13 during green signal time for Lane 12, Lane 13 and Lane 14 and inter signal green time, demand flow for Lane 13 during cycle time and excluding outgoing number of vehicles during green signal time for the Lane 13, exit flow for Lane 13 during cycle time. Equation 13 represents number of vehicles in Lane 21 at the end of cycle k (or beginning of cycle k+1) which is equivalent to the total of the number of vehicles waiting at the beginning of cycle k (from camera readings), incoming number of vehicles into the Lane 21 during green signal time for Lane 21, Lane 22 and Lane 24 and inter signal green time, demand flow for Lane 21 during cycle time and excluding outgoing number of vehicles during green signal time for the Lane 21, exit flow for Lane 21 during cycle time.

$$N_{11}(k+1)=N_{11}(k)+(g_{11}(k)+g_{12}(k)+g_{13}(k)+g_{14}(k)+4Ig)f_{11}(k)-g_{11}(k)s_{11}(k) \tag{9}$$

$$N_{12}(k+1)=N_{12}(k)+(g_{11}(k)+g_{12}(k)+g_{13}(k)+g_{14}(k)+4Ig)f_{12}(k)-g_{12}(k)s_{12}(k) \tag{10}$$

$$N_{13}(k+1)=N_{13}(k)+(g_{11}(k)+g_{12}(k)+g_{13}(k)+g_{14}(k)+4Ig)\Big[f_{13}(k)-e_{13}(k)+d_{13}(k)-g_{13}(k)S_{13}(k)\big/C_1\Big] \tag{11}$$

Her, $f_{13}(k)=t_{22}(k)s_{22}(k)+t_{23}(k)s_{23}(k)+t_{24}(k)s_{24}(k),\ e_{13}(k)=t_{13}(k)f_{13}(k),(g_{11}(k)+Ig)f_{13}(k)=0.$

$$N_{14}(k+1)=N_{14}(k)+(g_{11}(k)+g_{12}(k)+g_{13}(k)+g_{14}(k)+4Ig)f_{14}(k)-g_{14}(k)s_{14}(k) \tag{12}$$

$N_{21}(k+1) = N_{21}(k) + (g_{21}(k) + g_{22}(k) + g_{23}(k) + g_{24}(k) + 4Ig)\left[f_{21}(k) - e_{21}(k) + d_{21}(k) - g_{21}(k)S_{21}(k)\big/_{C_2}\right]$ (13)

Her, $f_{21}(k) = t_{11}(k)s_{11}(k) + t_{12}(k)s_{12}(k) + t_{14}(k)s_{14}(k),\ e_{21}(k) = t_{21}(k)f_{21}(k), (g_{23}(k) + Ig)f_{21}(k) = 0.$

$N_{22}(k+1) = N_{22}(k) + (g_{21}(k) + g_{22}(k) + g_{23}(k) + g_{24}(k) + 4Ig)f_{22}(k) - g_{22}(k)s_{22}(k)$ (14)

$N_{23}(k+1) = N_{23}(k) + (g_{21}(k) + g_{22}(k) + g_{23}(k) + g_{24}(k) + 4Ig)f_{23}(k) - g_{23}(k)s_{23}(k)$ (15)

$N_{24}(k+1) = N_{24}(k) + (g_{21}(k) + g_{22}(k) + g_{23}(k) + g_{24}(k) + 4Ig)f_{24}(k) - g_{24}(k)s_{24}(k)$ (16)

Lower and upper bounds of green signal time are given by,

$(g_{1j}(k))_{min} \leq g_{1j}(k) \leq (g_{1j}(k))_{max}$, $j = 1,2,3,4.$ (17)

$(g_{2j}(k))_{min} \leq g_{2j}(k) \leq (g_{2j}(k))_{max}$, $j = 1,2,3,4.$ (18)

Cycle time of cycle k is given by the total green signal time and total inter green signal time:

$(g_{11}(k) + Ig) + (g_{12}(k) + Ig) + (g_{13}(k) + Ig) + (g_{14}(k) + Ig) = C_1(k),$ (19)

$(g_{21}(k) + Ig) + (g_{22}(k) + Ig) + (g_{23}(k) + Ig) + (g_{24}(k) + Ig) = C_2(k).$ (20)

Lower and upper bounds of cycle time are given by,

$(CT_1)_{min} \leq C_1(k) \leq (CT_1)_{max}$, (21)

$(CT_2)_{min} \leq C_2(k) \leq (CT_2)_{max}.$ (22)

Special oversaturation condition is defined as the number of outgoing vehicles during green signal time in a lane at a given cycle is less than the number of vehicles in that lane at the end of that cycle. The following eight inequalities represent the special oversaturation conditions during cycle k for the Lane 11, Lane 12, Lane 13, Lane 14, Lane 21, Lane 22, Lane 23 and Lane 24 respectively:

$s_{11}(k)g_{11}(k) \leq N_{11}(k+1)$, (23)

$s_{12}(k)g_{12}(k) \leq N_{12}(k+1),$ (24)

$s_{13}(k)g_{13}(k) \leq N_{13}(k+1),$ (25)

$s_{14}(k)g_{14}(k) \leq N_{14}(k+1),$ (26)

$s_{21}(k)g_{21}(k) \leq N_{21}(k+1)$, (27)

$s_{22}(k)g_{22}(k) \leq N_{22}(k+1),$ (28)

$s_{23}(k)g_{23}(k) \leq N_{23}(k+1),$ (29)

$s_{24}(k)g_{24}(k) \leq N_{24}(k+1).$ (30)

The incoming number of vehicles into a lane during a cycle time is less than or equal to the outgoing number of vehicles from that lane during green signal time is considered as a condition. The following eight inequalities represent those conditions during cycle *k* for the Lane 11, Lane 12, Lane 13, Lane 14, Lane 21, Lane 22, Lane 23 and Lane 24 respectively:

$f_{11}(k)C_1(k) \leq s_{11}(k)g_{11}(k),$ (31)

$f_{12}(k)C_1(k) \leq s_{12}(k)g_{12}(k),$ (32)

$[f_{13}(k)(1 - e_{13}(k)) + d_{13}(k)](g_{12}(k) + g_{13}(k) + g_{14}(k) + 3Ig) \leq s_{13}(k)g_{13}(k),$ (33)

Here, $f_{13}(k) = t_{22}(k)s_{22}(k) + t_{23}(k)s_{23}(k) + t_{24}(k)s_{24}(k)$

$f_{14}(k)C_1(k) \leq s_{14}(k)g_{14}(k),$ (34)

$[f_{21}(k)\big(1 - e_{21}(k)\big) + d_{21}(k)](g_{21}(k) + g_{22}(k) + g_{24}(k) + 3Ig) \leq s_{21}(k)g_{21}(k),$ (35)

Here, $f_{21}(k) = t_{11}(k)s_{11}(k) + t_{12}(k)s_{12}(k) + t_{14}(k)s_{14}(k)$

$f_{22}(k)C_2(k) \leq s_{22}(k)g_{22}(k),$ (36)

$f_{23}(k)C_2(k) \leq s_{23}(k)g_{23}(k),$ (37)

$f_{24}(k)C_2(k) \leq s_{24}(k)g_{24}(k).$ (38)

2.2 Flow chart of the model and the method of solution

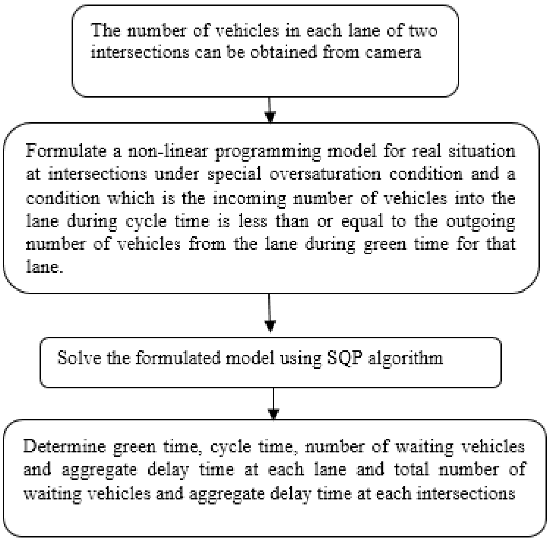

Fig.4. Flow chart for the model and the method of solution

III. Optimize Green Time

Objective is to minimize the total number of vehicles waiting at the intersections subject to the oversaturation condition, the delay, additional condition and some constraints related to the traffic signal control problem, which are described above, are combined into the model formulation and is illustrated below to calculate the duration of the green signal time on at the beginning of the cycle k:

Minimize $Z = \sum_{j=1}^{8}\sum_{i=1}^{2} W_{ij}\, N_{ij}(k+1)$

Subject to

$$s_{ij}(k)g_{ij}(k) \le N_{ij}(k+1),\ i = 1,2,\ j = 1,2,3,4$$
$$f_{11}(k)C_1(k) \le s_{11}(k)g_{11}(k),$$
$$f_{12}(k)C_1(k) \le s_{12}(k)g_{12}(k),$$
$$[f_{13}(k)(1-e_{13}(k)) + d_{13}(k)](g_{12}(k) + g_{13}(k) + g_{14}(k) + 3Ig) \le s_{13}(k)g_{13}(k),$$
$$f_{14}(k)C_1(k) \le s_{14}(k)g_{14}(k),$$
$$[f_{21}(k)\big(1-e_{21}(k)\big) + d_{21}(k)](g_{21}(k) + g_{22}(k) + g_{24}(k) + 3Ig) \le s_{21}(k)g_{21}(k),$$
$$f_{22}(k)C_2(k) \le s_{22}(k)g_{22}(k),$$
$$f_{23}(k)C_2(k) \le s_{23}(k)g_{23}(k),$$
$$f_{24}(k)C_2(k) \le s_{24}(k)g_{24}(k).$$
$$(g_{ij}(k))_{min} \le g_{ij}(k) \le (g_{ij}(k))_{max},\ i = 1,2,\ \ j = 1,2,3,4.$$
$$(CT_i)_{min} \le C_i(k) \le (CT_i)_{max},\ i = 1,2$$
$$(g_{i1}(k) + Ig) + (g_{i2}(k) + Ig) + (g_{i3}(k) + Ig) + (g_{i4}(k) + Ig) = C_i(k), i = 1,2$$

The cycle time is equal to the sum of the total green signal time and total inter green time. Each green time value has a minimum value ($(g_{ij}(k))_{min}$) and a maximum value ($(g_{ij}(k))_{max}$) which are fixed for a cycle.

In order to maintain the feasibility, the sum of the total minimum green signal time values and inter green signal time values is assumed to be greater than or equal to $(CT_i)_{min}, i = 1,2$ and also, the sum of the total maximum green signal time values and inter green signal time values is assumed to be less than or equal to $(CT_i)_{max}. i = 1,2.$

The objective function consists of waiting parameters $W_{ij}, i = 1,2$, j = 1, 2, 3, 4 assigned to each lane at each intersection. The default value of $W_{ij}, i = 1,2$,j = 1, 2, 3, 4 is assigned to 1. The objective function can be optimized by selecting different waiting parameters W_{ij} according to different criteria: lane priority, emergency vehicle passing etc.

To optimize green time for each signal we apply sequential quadratic programming algorithm implemented in the MATLAB optimization toolbox for the above nonlinear programming problem.

IV. Results And Discussion

The method is tested to a hypothetical data set:

Distance between Intersection 1 and Intersection 2 is 600m. Average length of a small vehicle is approximately 5 m. So the number of vehicles in Lane 13 and Lane 21 is less than 120.

Distance between upstream camera and downstream camera installed in any lane is 300 m. If we assume that the average length of a small vehicle is approximately 5 m, then the maximum number of vehicles in a lane within 300 m is 60.
Incoming flow rates of vehicles for the lanes are fixed over the cycles is given by
f_{ij}=0.1 $vehicles\ /sec., i = 1,2,\ j = 1,2,3,4.$
Outgoing flow rates of vehicles for the lanes are fixed over the cycles is given by
s_{ij}= $0.5 vehicles/sec., i = 1,2,\ j = 1,2,3,4.$
Inter green signal time is given by
Ig=1 sec.
Weighting parameters of the lanes are given by
W_{ij}=1 for $i = 1,2,\ j = 1,2,3,4.$
Vehicle turning rates are fixed over the cycles:
$t_{11} = 0.55, t_{12} = 0.12, t_{14} = 0.05, t_{22} = 0.05, t_{23} = 0.55, t_{24} = 0.12.$
Saturation flow rates are fixed over the cycles:

$$S_{13}(k) = 0.5, S_{21}(k) = 0.5.$$

Vehicle exit flow are fixed over the cycles:

$$e_{13} = 0.6, e_{21} = 0.6.$$

Vehicle demand flow are fixed over the cycles:

$$d_{13} = 0, d_{21} = 0.$$

The upper bound of cycle time is fixed to 90 sec. The lower bound of cycle time is attained according to the model. Similarly, the upper bound and lower bound of green signal times are attained according to the model.

Simulation results are given in the following Table 1 for scenario 1:
From camera readings: $N_{11}(1) = 10,\ N_{12}(1) = 22,\ N_{13}(1) = 11,\ N_{14}(1) = 23$
$N_{21}(1) = 12,\ N_{22}(1) = 24,\ N_{23}(1) = 13,\ N_{24}(1) = 25$
Phase sequence order (signal order):
Intersection 1: Lane 12 signal, Lane 14 signal, Lane 11 signal, Lane 13 signal
Intersection 1: Lane 22 signal, Lane 24 signal, Lane 21 signal, Lane 23 signal

Table 1. Cycles and the optimum feasible results for scenario 1

Cycle k	Number of vehicles in lanes at each intersection and total of that at the beginning of the cycle $N_{1j}(k)\ [NT_1(k)]$ $N_{2j}(k)\ [NT_2(k)]$ $j = 1,2,3,4$	Green signal time (sec.) at each intersection $t_{1j}(k)$ $t_{2j}(k)$ $j = 1,2,3,4$	Cycle time (sec.) $C_1(k)$ $C_2(k)$	Aggregate delay time and total of that at each intersection at the end of the cycle (sec.) $D_{1j}(k+1)\ [DT_1(k+1)]$ $D_{2j}(k+1)\ [DT_2(k+1)]$ $j = 1,2,3,4$	Number of vehicles in lanes at each intersection at the end of the cycle. $N_{1j}(k+1)$ $N_{2j}(k+1)$ $j = 1,2,3,4$
1	15 10 14 18 [57] 15 10 09 16 [50]	19 18 17 24 19 18 17 24	82 82	1189 434 1385 889 [3897] 18085 434 969 725 [20212]	14 09 14 14 15 09 09 12
2	14 09 14 14 [51] 15 09 09 12 [45]	19 16 16 19 19 16 16 19	74 74	893 367 1165 703 [3129] 14177 367 823 555 [15923]	12 08 14 12 14 08 08 10
3	12 08 14 12 [46] 14 08 08 10 [40]	17 14 14 16 17 14 14 16	65 65	653 293 1005 558 [2509] 10240 293 643 428 [11603]	10 08 14 11 13 08 08 09
4	10 08 14 11 [43] 13 08 08 09 [38]	16 14 14 15 16 14 14 15	63 63	529 266 959 512 [2266] 9226 266 602 386 [10480]	08 07 14 10 12 07 07 08
5	08 07 14 10 [39] 12 07 07 08 [34]	13 12 12 13 13 12 12 13	54 54	385 203 818 402 [1808] 6610 203 449 294 [7557]	07 06 14 09 11 06 06 07
6	07 06 14 09 [36] 11 06 06 07 [30]	12 11 11 12 12 11 11 12	50 50	311 155 756 333 [1555] 5229 155 364 233 [5981]	06 06 14 08 10 06 06 06
7	06 06 14 08 [34] 10 06 06 06 [28]	10 10 10 10 10 10 10 10	44 44	249 139 653 282 [1323] 3907 139 304 194 [4544]	05 05 14 07 10 05 05 05
8	05 05 14 07 [31] 10 05 05 05 [25]	09 09 09 09 09 09 09 09	40 40	190 100 593 225 [1108] 3279 100 235 145 [3759]	05 05 14 07 10 05 05 05
9	05 05 14 07 [31] 10 05 05 05 [25]	09 09 09 09 09 09 09 09	40 40	190 100 593 225 [1108] 3279 100 235 145 [3759]	05 05 14 07 10 05 05 05

In the Table 1 given above, the results of cycle 8 and cycle 9 are the same. If this process continues into more cycles, the results will be the same as the results of cycle 8. Because of oversaturation situation some vehicles are still waiting in each lane in the last cycle (cycle 8).

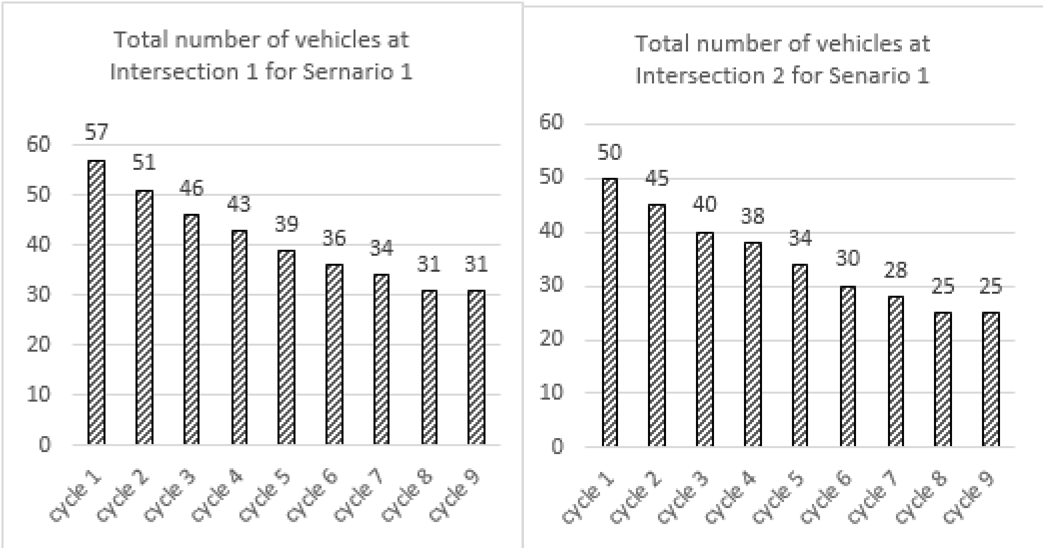

Fig 4. Total number of vehicles at each cycle in Intersection 1 and Intersection 2 for scenario 1.

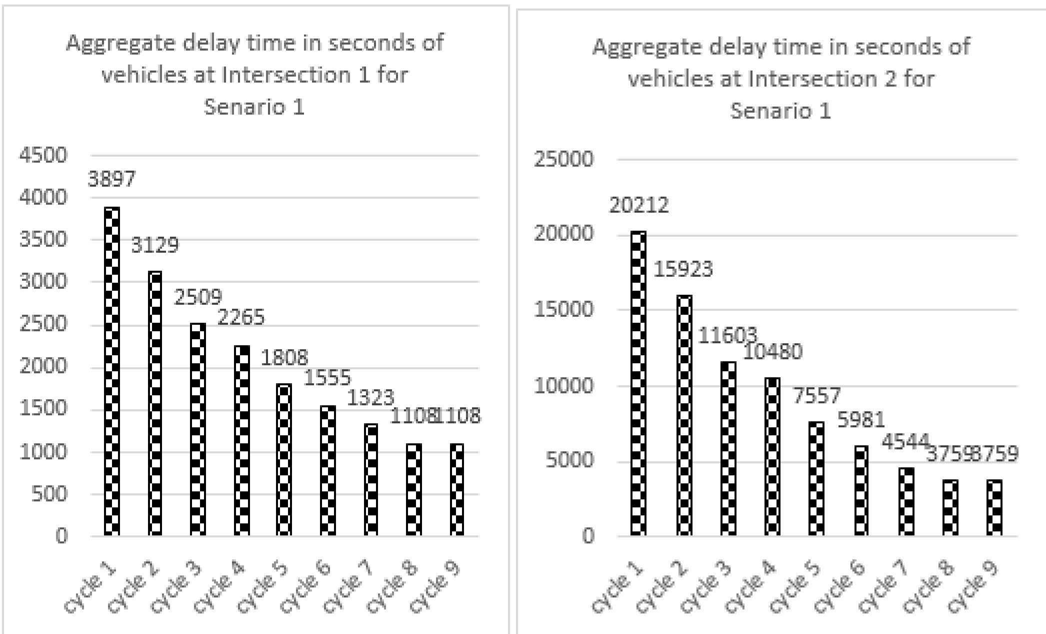

Fig.5. Aggregate delay time at each cycle at Intersection 1 and Intersection 2 for scenario 1.

Simulation results are given in the following Table 2 for scenario 2:
From camera readings: $N_{11}(1) = 42,\ N_{12}(1) = 44,\ N_{13}(1) = 28,\ N_{14}(1) = 26,$
$N_{21}(1) = 25,\ N_{22}(1) = 55,\ N_{23}(1) = 24,\ N_{24}(1) = 34$
Phase sequence order (signal order):
Intersection 1: Lane 12 signal, Lane 14 signal, Lane 11 signal, Lane 13 signal
Intersection 1: Lane 22 signal, Lane 24 signal, Lane 21 signal, Lane 23 signal

Table 2. Cycles and the optimum feasible results for scenario 2

Cycle k	Number of vehicles in lanes at each intersections and total of that at the beginning of the cycle $N_{1j}(k)$ $[NT_1(k)]$ $N_{2j}(k)$ $[NT_2(k)]$ $j = 1,2,3,4$					Green signal time (sec.) at each intersections $t_{1j}(k)$ $t_{2j}(k)$ $j = 1,2,3,4$				Cycle time (sec.) $C_1(k)$ $C_2(k)$	Aggregate delay time and total of that at each intersections at the end of the cycle (sec.) $D_{1j}(k+1)$ $[DT_1(k+1)]$ $D_{2j}(k+1)$ $[DT_2(k+1)]$ $j = 1,2,3,4$					Number of vehicles in lanes at each intersections at the end of the cycle. $N_{1j}(k+1)$ $N_{2j}(k+1)$ $j = 1,2,3,4$			
01	42	44	28	26	[140]	25	18	24	18	89	3332	3583	2364	2152	[11431]	38	44	25	26
	25	55	24	34	[138]	25	18	24	18	89	36179	4562	2100	2864	[45705]	22	55	21	34
02	38	44	25	26	[133]	25	18	24	18	89	2976	3583	2097	2152	[10808]	34	44	22	26
	22	55	21	34	[132]	25	18	24	18	89	31187	4562	1833	2864	[40446]	19	55	18	34
03	34	44	22	26	[126]	23	18	26	18	89	2736	3583	1748	2152	[10219]	31	44	18	26
	19	55	18	34	[126]	23	18	26	18	89	28583	4562	1451	2864	[37460]	16	55	14	34
04	31	44	18	26	[119]	20	21	22	21	88	2670	3296	1650	1943	[9559]	30	42	17	24
	16	55	14	34	[119]	20	21	22	21	88	24141	4264	1294	2647	[32345]	15	53	12	32
05	30	42	17	24	[113]	19	22	21	22	88	2657	3043	1639	1721	[9051]	29	40	16	22
	15	53	12	32	[112]	19	22	21	22	88	22990	4011	1173	2416	[30590]	15	51	10	30
06	29	40	16	22	[107]	20	23	19	23	89	2569	2833	1687	1507	[8596]	28	37	16	19
	15	51	10	30	[106]	20	23	19	23	89	21874	3812	1133	2219	[29038]	15	48	09	27
07	28	37	16	19	[100]	20	23	18	23	88	2446	2526	1705	1218	[7895]	27	34	17	16
	15	48	09	27	[99]	20	23	18	23	88	20843	3494	1072	1922	[27331]	15	45	09	24
08	27	34	17	16	[94]	20	23	18	23	88	2358	2262	1793	954	[7366]	26	31	18	13
	15	45	09	24	[93]	20	23	18	23	88	20843	3230	1072	1658	[26803]	15	42	09	21
09	26	31	18	13	[88]	20	25	18	22	89	2312	1878	1922	794	[6906]	25	27	19	11
	15	42	09	21	[87]	20	25	18	22	89	21356	2857	1098	1506	[26817]	15	38	09	19
10	25	27	19	11	[82]	20	27	18	20	89	2223	1370	2011	767	[6371]	24	22	20	10
	15	38	09	19	[81]	20	27	18	20	89	21356	2349	1098	1479	[26282]	15	33	09	18
11	24	22	20	10	[76]	20	28	18	19	89	2134	850	2100	753	[5837]	23	17	21	09
	15	33	09	18	[75]	20	28	18	19	89	21356	1829	1098	1465	[25748]	15	28	09	17
12	23	17	21	09	[70]	19	25	17	17	82	1845	509	1959	646	[4959]	22	13	21	09
	15	28	09	17	[69]	19	25	17	17	82	18085	1411	969	1302	[21766]	15	24	09	17
13	22	13	21	09	[65]	19	20	16	16	75	1520	419	1723	551	[4213]	20	11	21	09
	15	24	09	17	[65]	19	20	16	16	75	14584	1244	847	1151	[17826]	14	22	09	17
14	20	11	21	09	[61]	18	18	16	16	72	1327	355	1621	490	[3793]	18	09	21	08
	14	22	09	17	[62]	18	18	16	16	72	12900	1147	778	1066	[15891]	13	20	08	16
15	18	09	21	08	[56]	16	15	14	14	63	1033	274	1400	378	[3085]	16	08	21	07
	13	20	08	16	[57]	16	15	14	14	63	9226	967	602	882	[11677]	12	19	07	15
16	16	08	21	07	[52]	15	13	12	12	56	785	233	1242	310	[2570]	14	07	21	07
	12	19	07	15	[53]	15	13	12	12	56	6489	849	484	758	[8580]	11	18	07	15
17	14	07	21	07	[49]	14	12	12	12	54	668	203	1185	281	[2337]	12	06	21	06
	11	18	07	15	[51]	14	12	12	12	54	5736	797	449	713	[7695]	10	17	06	14
18	12	06	21	06	[45]	12	10	10	10	46	485	158	1006	213	[1862]	11	06	21	06
	10	17	06	14	[47]	12	10	10	10	46	3832	664	333	581	[5410]	09	17	06	14
19	11	06	21	06	[44]	11	10	10	10	45	455	149	984	204	[1792]	10	06	21	06
	09	17	06	14	[46]	11	10	10	10	45	3466	644	319	564	[4993]	08	17	06	14
20	10	06	21	06	[43]	10	10	10	10	44	425	139	961	194	[1719]	09	05	21	05
	08	17	06	14	[45]	10	10	10	10	44	3115	623	304	546	[4588]	08	16	05	13
21	09	05	21	05	[40]	10	09	09	09	41	336	108	895	153	[1492]	08	05	21	05
	08	16	05	13	[42]	10	09	09	09	41	2579	559	248	481	[3867]	07	16	05	13
22	08	05	21	05	[39]	09	09	09	09	40	310	100	873	145	[1428]	08	05	21	05
	07	16	05	13	[41]	09	09	09	09	40	2289	540	235	465	[3529]	07	16	05	13
23	08	05	21	05	[39]	09	09	09	09	40	310	100	873	145	[1428]	08	05	21	05
	07	16	05	13	[41]	09	09	09	09	40	2289	540	235	465	[3529]	07	16	05	13

In Table 2 given above, the results of cycle 22 and cycle 23 are the same. If this process continues more cycles, the results will be same as the results of cycle 22. Because of oversaturation situation, some vehicles are still waiting in each lane in the final cycle (cycle 22).

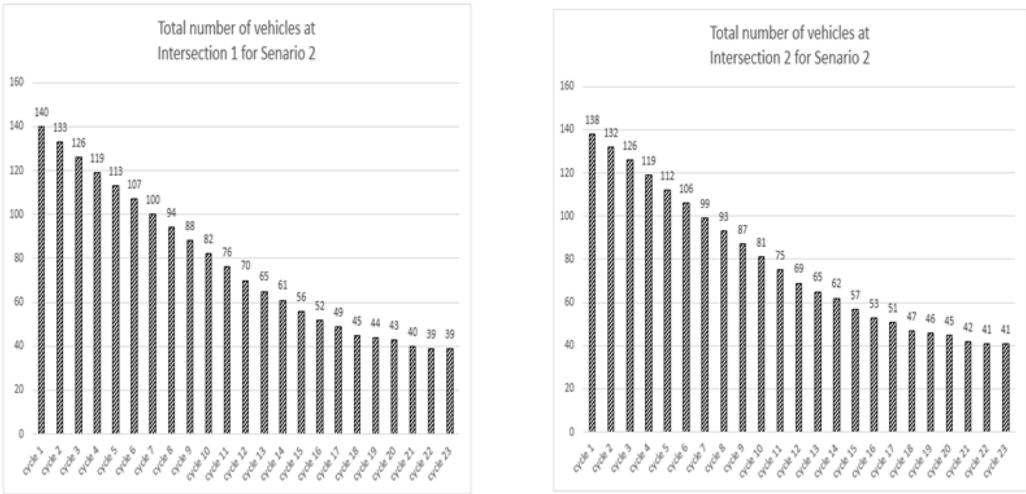

Fig 6. Total number of vehicles at each cycle in Intersection 1 and Intersection 2 for scenario 2.

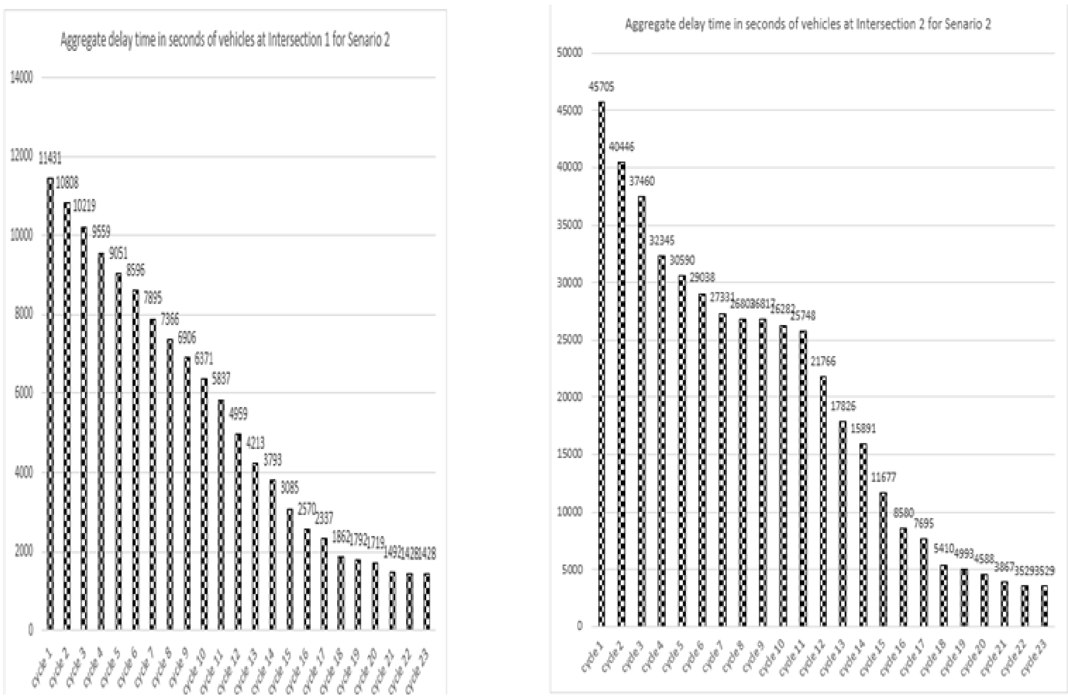

Fig.7. Aggregate delay time at each cycle at Intersection 1 and Intersection 2 for scenario 2.

V. Conclusion

A non-linear programming optimization model is established to minimize the real time traffic signal control efficiency such as total number of vehicles and aggregate delay time of vehicles at two intersections of a road arterial network. This model can be extended to more than two intersections arterial networks. A flow-chart is designed to solve the model with the help of MATLAB optimization toolbox. Entering vehicles to the road intersections is counted using cameras installed in the lanes of road intersections which is confirmed to be a valuable technique widely used around the world. This model includes inter green signal time. Our proposed model offers more practical solution than the existing developed models. The method is tested using hypothetical data sets and considered two situations. Results are given in Table 1 and Table 2. It can be observed that the total number of vehicles waiting in each lane and total number of vehicles waiting in each intersection decrease from one cycle to another. Subsequently, the aggregate delay time of vehicles at each intersection also decreases. Finally, it can be concluded that the proposed model is providing a promising result which can be practically implemented at road arterial networks consist of two intersections.

References

[1]. Olia, A.; Abdelgawad, H.; Abdulhai, B.; Razavi, S.N. Assessing the Potential Impacts of Connected Vehicles: Mobility, Environmental, and Safety Perspectives. J. Intell. Transp. Syst. Technol. Plan. Oper. 2014, 23, ix–xii

[2]. Transportation Research Board. Signal timing practices and procedures-state of the practice [R]. Washington, DC: National Research Council, 2005.

[3]. SUN Wei-li, WU Xin-kai, WANG Yun-peng, YU Gui-zhen. A continuous- flow-intersection-lite design and traffic control for oversaturated bottleneck intersections [J]. Transportation Research Part C, 2015, 56: 18−33.

[4]. Tang-Hsien Chang, Jen-Ting Lin, August 2000."Optimal signal timing for an oversaturated intersection" Transportation Research Part B 34(2000)471-491.

[5]. AKCELIK. R. (1980). Time dependent Expressions for Delay, Stop Rate and Queue Length at Traffic signals. Internal Report. AIR 367-1. Australian Road Research Board,Vermount South, Australia.

[6]. Papageorgiou, M. and Kosmatopoulos, E. (2009) Store-and-forward based methods for the signal control problem in large-scale congested urban road networks. Transportation Research Part C: Emerging Technologies, 17(2), pp. 163-174.

[7]. Liu F, Zeng Z, Jiang R (2017) Avideobased real-time adaptive vehicle-counting system for urban roads.PLoS ONE 12(11):e0186098.

[8]. AhmetYazici, GangdoSeo, UmitOzguner, A model predictive control approach for decentralized traffic signal control, Proc. 17th World Congress, The international federation of Automatic Control, Seoul, Korea, July 6-11, 2008.

Yogeswary Raviraj "Real Time Traffic Control to Optimize Waiting Time of Vehicles at Road Arterial Networks "International Journal of Engineering Science Invention (IJESI), vol. 07, no. 07, 2018, pp 48-58