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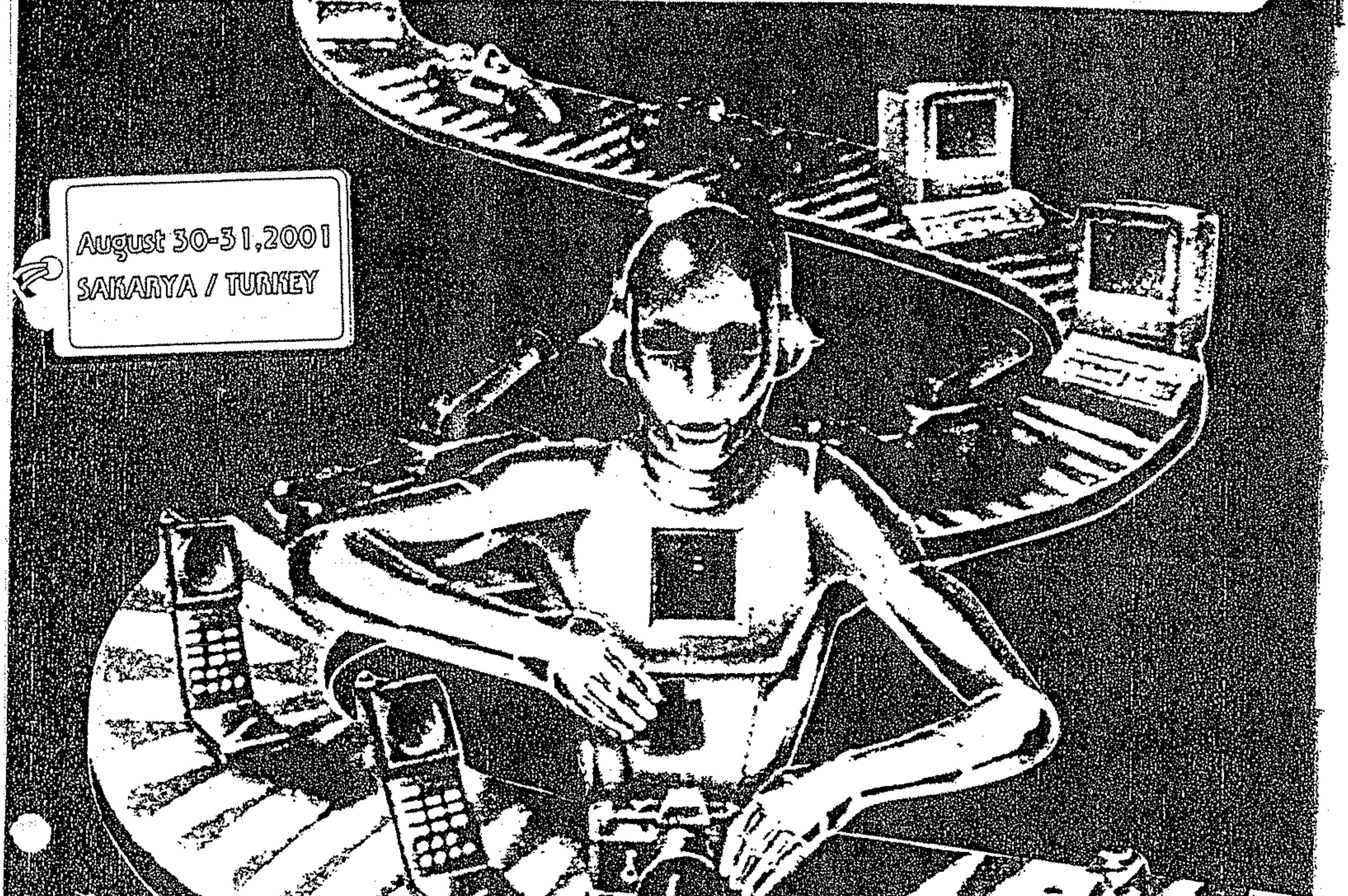
"Visions for the Future"

3rd INTERNATIONAL SYMPOSIUM ON INTELLIGENT MANUFACTURING SYSTEMS

August 30-31,2001
SAKARYA / TURKEY



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SIMULATION BASED OPTIMIZATION OF CYCLE TIME AND GREEN SPLITS AT CRITICAL INTERSECTIONS

Ahmet AKBAS
e.mail: akbas@marun.edu.tr

Mehmet TEKTAS
e.mail: tektas@marun.edu.tr

Vocational High School of Technical Sciences, University of Marmara
81040 Göztepe Kampusu - Istanbul-TURKIYE Tel: 0-216-4182504 / 614-621
Fax: 0-216-4182505

Abstract

In this study a simulation based experiment has been realized to evaluate a dynamic optimization method which can be used in critical intersection signal controllers. By using VAP programming language commands, developed optimization algorithms have been transferred to VISSIM simulation environment to optimize a critical intersection model. Through the simulation, calculation of degrees of saturation for each traffic flow has been done by using an algorithm which is based on time headway measurements accepted from loop detectors. Also, other related algorithms have been used for cycle based iterative optimization of cycle time and green splits. These algorithms have been developed by a method based on evaluation of calculated degrees of saturation values. Under the various saturated traffic compositions, simulation results have shown that variations of average degrees of saturation of total flows can be smoothened and average degree of saturation of intersection can be maintained near the practical degree of saturation (0.7-0.9) which corresponds to optimum volume and performance of the critical intersection model.

1-Introduction

Degrees of saturation about traffic flows have big divergences in a day at some parts of the urban traffic networks. Also, some of the signalized intersections, which are called *critical intersection* by many of traffic control strategies, have a special importance because of their variable and saturated traffic flow characteristics (Bielefeldt and Busch 1994; Hunt. Robertson, Bretherton and Royle 1982; Lowrie, P.R. 1982; Miyata and Usami 1996). So. in order to control the urban traffic networks, traffic control system must be suitable to the physical and geographical conditions of urban traffic environment. Within this requirement, it is important to optimize the volume and performance values of critical intersections at saturated traffic conditions.

From a different point of view, the volume and performance values depend on signal timing parameters at signalized intersections. That means, it is important to optimize the signal timing parameters at critical intersections by using on-line optimization techniques. On the other hand it is known that, optimal volume and performance values of an intersection can be established if its average degree of saturation can be maintained as a *practical degree of saturation* value (Akçelik, 1995).

Within this relation, in this study a simulation based experiment has been realized to evaluate a dynamic optimization method which can be used in critical intersection signal controllers. Through the simulation, calculation of average degrees of saturation for each flow has been done by using an algorithm which is based on time headway measurements accepted from loop detectors. Also, two other algorithms have been used for cycle based

SCIENTIFIC PROGRAM

THURSDAY (August 30, 2001)

09:00-09:30	Openning Speeches

09:30-10:30	Keynote Speaker (L. A. Zadeh)

11:00-12:40	Parallel Sessions I

Production/Process Planning I Chairman:Assoc.Proff.Dr.O.TORKUL Session Hall: A

[21] **Integration of CAD and Generative CAPP Based on Feature,** Janusz POBAZNİAK
[41] **A Constraint Based Operation Sequencing for a Knowledge-Based Process Planning,** Cevdet GÖLOĞLU
[42] **Concurrent Engineering Utilities for Controlling Interactions in Process Planning,** Türkay Dereli, Adil Baykasoğlu
[43] **Controller Area Network (CAN) for Computer Integrated Manufacturing Systems,** Nilüfer (YANIK) ÇENESİZ, E. Murat ESİN
[93] **An Integrated Real Time MRP and Group Technology System,** Orhan TORKUL, İsmail Calli

Scheduling I Chairman:Proff.Dr.Braithwaite Session Hall:B

[36] **An Assembly Sequence Planning with an Ordered List of Task Representations,** Cem SİNANOĞLU, Eyüp Sabri TOPAL
[37] **Fuzzy Branch-and-Bound Algorithm For Flowshop Scheduling,** İzzettin TEMİZ, Serpil EROL
[38] **An Extension To Path Algebra Applications in Shortest Path Problem to Solve Sequencing Problem,** Mustafa YURDAKUL , George R. WILSON
[83] **Knowledge Based Scheduling for Complex Problems,** Ercan ÖZTEMEL, Hatice KOLAY

Optimization Chairman:Asst.Proff.Dr.T.Dereli Session Hall: C

[23] **Simulation Baseed Optimization of Cycle Time and Green Splits at Critical Intersections,** Ahmet Akbaş, Mehmet Tektaş
[24] **Optimisation of Resistive Loading of EMI/EMC Near Field Probe,** Selçuk ÇÖMLEKÇİ, Şükrü ÖZEN, Etem KÖKLÜKAYA
[25] **Finite Elements Analysis And Application Work for a Plastic Injected Experimental Part,** Babür ÖZÇELİK, Tuncay ERZURUMLU, Murat BÜYÜK
[26] **Sliding Mode Control of Three Dimensional Jointed Manipulator For Constrain Path,** Recep BURKAN, İbrahim UZMAY
[74] **Modeling of BASIC OXYGEN FURNACE(BOF):A Mathematical and Fuzzy Approach,** Harun TASKIN, Cemalettin KUBAT, Recep Artış, Ayten Yılmaz

Control I Chairman: Proff.Dr.B.Can Session Hall: D

[72] **Training of Fuzzy Systems Based On Gradient Algorithms and Performance Comparison,** Musa ALCI
[07] **Straight-Line Trajectory Generation and Inverse Dynamic Control Of Three Dimensional Jointed Manipulator,** Recep BURKAN, İbrahim UZMAY
[09] **Straight-LineTrajectory Generation And Inverse Dynamic Control Of Two-Link Planar Manipulator,** Recep BURKAN, İbrahim UZMAY
[10] **Joint Space Trajectory Generation And Adaptive Control Of The Three Dimensional Jointed Manipulator,** Recep BURKAN, İbrahim UZMAY
[16]] **Neurocontrol of Air Speed of a HVAC Experimental Room,** Ahmet Emin Kuzucuoğlu, Burhanettin Can, Hasan Erdal

iterative optimization of cycle time and green splits. These two algorithms have been developed by a method based on evaluation of calculated degrees of saturation values.

Then, in order to optimize a critical intersection model, algorithms have been transferred to VISSIM simulation environment by using VAP programming language commands. Through the 4 hours of simulation which have been realized under the same conditions both at VAP control mode and fixed time control mode, vehicle inputs have been changed automatically at beginning of each simulation hour. Results have been arranged as different graphics to show the realized cycle time, two sample of green splits and variations of average degrees of saturation for both total flows and flow which have maximum average degrees of saturation in cycle basis.

2- Performance Considerations

The intersection degree of saturation, X, is defined as the largest degree of saturation of incoming flows. Because of that, the condition for the intersection that $X<1$ satisfies the condition $x<1$ for all incoming flows. In practice, there is an acceptable maximum degree of saturation which must be less then 1.0 because traffic conditions become unstable as arrival flows approach capacity resulting in excessive delays, stops and queue lengths. This is called *practical degree of saturation,* and is denoted by x_p for a flow and X_p for an intersection. (Akçelik R, 1995)

A study of various operating characteristics such as delay, number of stops and queue length with respect to increasing degrees of saturation indicates that practical degree of saturation in the range from 0.8 to 0.9 represent satisfactory operating conditions (Akçelik, 1995). A value of 0.9 is implied in Webster and Cobbe (1966). Although a value of 0.95 represents undesirable operating conditions (long delays, unstable queues, etc.), this can be used as an absolute practical limit to under saturated operating conditions. Therefore, a value less than 0.9 may be chosen depending on the particular peaking characteristics during the design/control period.

On the other hand, the capacity and degree of saturation are more basic measures of performance. Capacity means the maximum volume of intersection. The degree of saturation can therefore be used to determine the pattern of change in delay, number of stops and queue length. The intersection performance deteriorates rapidly at degrees of saturation above 0.8 to 0.9. The degree of saturation can therefore be used as a simple indicator of signalized intersection level of service (Akçelik R, 1979).

That is, optimal volume and performance values can be established if average degree of saturation of intersection is maintained as a practical degree of saturation through the control process.

3-Intersection Model

In order to determine the cycle time and green splits, the ways that traffic flows follow while they are incoming and outgoing the intersection must be identified first so that an intersection model must be created. In this study the NEMA flow scheme has been used. In a four armed intersection this scheme includes 8 different flows with east-west and south-north directions. For each arm, straight going flow and left turning flow are defined. Figure 1a shows the intersection model with 8 different flows that obeys NEMA scheme.

In the urban traffic networks intersections generally have three or four arms so this model can be accepted by a general model for urban intersection structures and for critical intersection structures. (Transyt 7F Users Guide, 1998)

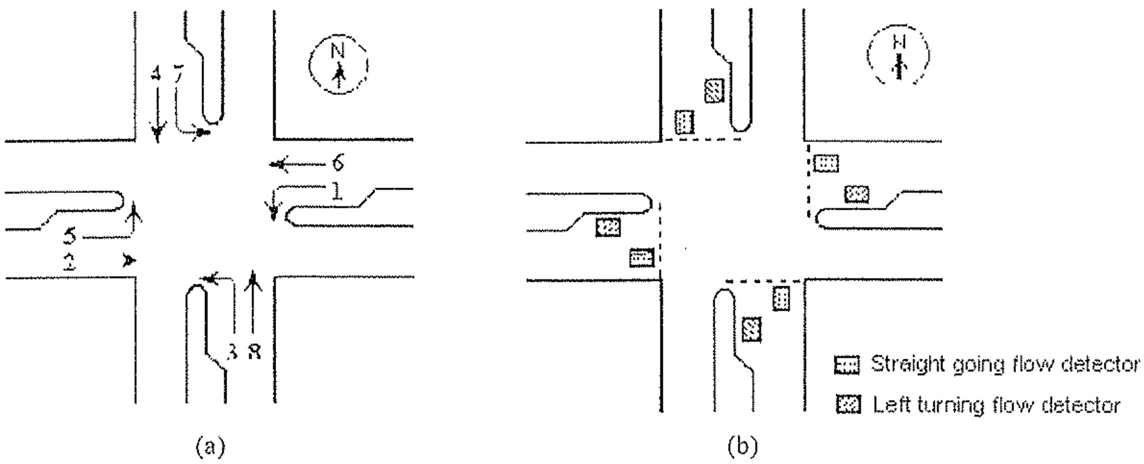

Figure 1. (a) *Identifying 8 different flow due to NEMA flow scheme for model intersection.* (b) *Placement of loop detectors for measuring the flow parameters.*

4-Formation of Signal Timing Plan

According to NEMA flow scheme phase systems of a 4-armed intersection can be arranged in different ways. Arrangement of the phases depends on designer assumptions and starting flow for different phases. It is obvious that phase sequences can be changed according to the calculated green split values in a dynamic signal control process.

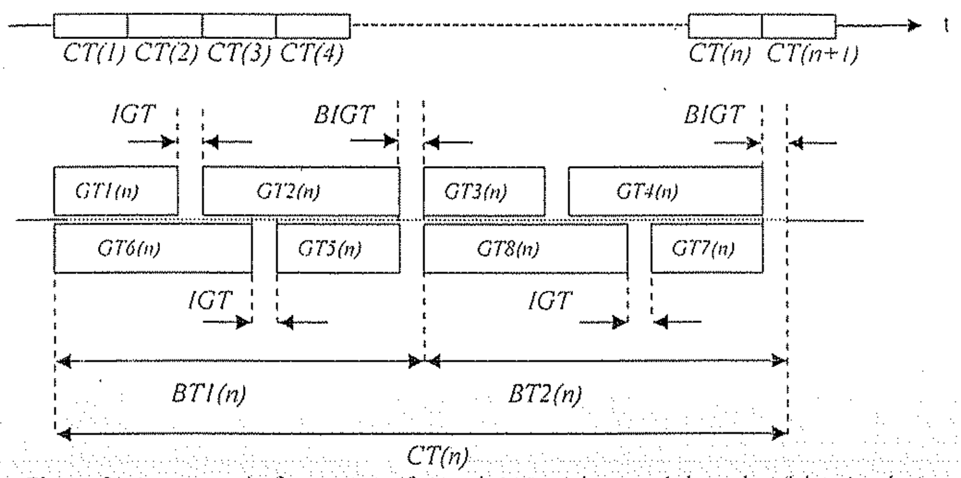

Figure 2- An example *formation of signal timing plan at n' th cycle of the simulation.*

In this study the beginning phase arrangement for the simulation process has been chosen as in Figure 2. In this arrangement starting flows have been chosen as flows 1 and 6 in east-west direction and flows 3 and 8 in south-north direction. This arrangement has been specially chosen in consideration of forthcoming study about coordination of neighboring intersections forming sub areas.

Figure 2 shows the timing parameters at n'th cycle index. Here, *CT(n)* shows the cycle time which includes inter-green times (*IGT*) and barrier inter-green times (*BIGT*). *GTi(n)* shows the green split time for signal group 'i' which corresponds to permission of flow 'i' (1....8), *BT1(n)* and *BT2(n)* show the barrier time for flows in east-west and in south-north directions. These two notations include inter-green time (*IGT*) and barrier inter-green time (*BIGT*). For all these notations 'n' shows the cycle index.

In formation of signal timing plan, it is important first to satisfy the safety rules. For this reason, conflicting flows must not have the right of way in the same time. So, this rule has been carefully adapted to both the formation of signal timing and to the calculation algorithms. In Figure 2 it is shown that, the flow pairs 1-2 and 5-6 in the east-west direction and the flow pairs 3-4 and 7-8 in the south-north direction are conflicting flows. These pairs of flows don't have the right of the way at the same time.

5- Measuring The Flow Parameters

In the on-line optimization algorithms for determining the cycle time and green splits, the beginning action is calculation of average degrees of saturation for each flow by using flow parameter measurements. For making flow parameter measurements virtual inductive loop detectors have been used in simulation environment. Loop detectors have been set near the stop line for each lane as shown in Figure 1b.

The two important flow measurements are time *headway* and *occupancy*. Occupancy is a time period in which a vehicle occupy the loop detector. Also headway is a time period in which no vehicle occupy the loop detector. An example to the occupancy and headway distribution pattern through the loop detector in any green split has been shown in Figure 3.

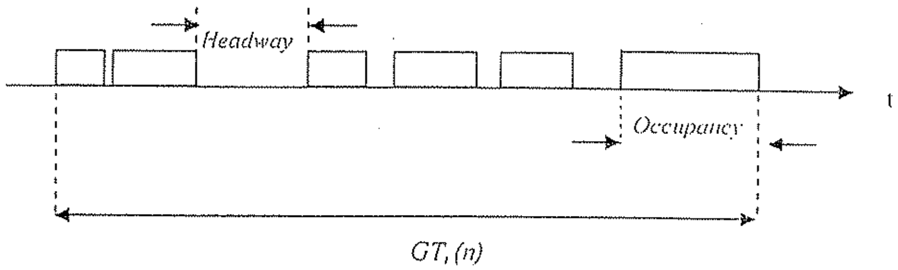

Figure3- *An example occupancy and headway distribution pattern accepted from the loop detector*

6- Calculation Algorithm for Average Degree of Saturation

In the VISSIM simulation environment on-line control of the model intersection has been realized by using cycle time and green splits optimization algorithms which are formed as a VAP programming language file. The developing of these two algorithms have been based on evaluation of calculated average degrees of saturation for each different flow. For this reason, calculation algorithm for average degrees of saturation has been developed first as in following paragraphs. The developing this algorithm has been based on evaluation of accepted headway-occupancy pattern from the loop detector through the green time split.

Through the simulation. degrees of saturation are calculated for each different flow at the end second of the cycle time in each cycle index within the following algorithm :

i. Headway sum and headway count values are cleared at the beginning of green split for each flow; $T_i(n) = 0$, $N_i(n) = 0$,

ii. Measured headway values are added to headway sum and headway counts are added to vehicle count value through the green split for each flow; $T_i(n)$, $N_i(n)$

iii. Effective green time value has been calculated for each green split,

$$GT'_i(n) = T_i(n) - N_i(n) * t_{min} \qquad (6.1)$$

iv. Average degree of saturation values are calculated for each flow at the end second of cycle.

$$x_i(n) = GT'_i(n) / GT_i(n) \qquad (6.2)$$

Here. i represents the flow identifier, n represents the step index or cycle index number, t_{min} represents the minimum headway between the following two vehicle which corresponds to maximum degree of saturation (x=1), $x_{i(n)}$ represents the average degree of saturation. $GT_{i(n)}$ the green time, $GT'_{i(n)}$ the effective green time, $T_{i(n)}$ the headway sum and $N_{i(n)}$ the vehicle count.

7-Cycle Time Optimization Algorithm

At the beginning of the simulation process first a default cycle time and default green splits have been assigned. Through simulation process the next cycle time, which is expected as optimum cycle time, is assigned as new cycle time value at the beginning of each cycle index. At the end of the each cycle the highest average degree of saturation of the flows and current cycle time must be taken into account to calculate the next cycle time. However the change in the cycle time must be important if calculation results are over an increasing value which is chosen as 5 seconds in this study. Operations can be made in the algorithmic structure of the cycle time calculation process as the following paragraphs:

i. Flow parameters are evaluated in average degree of saturation algorithm so that calculated highest one is used for the cycle time calculation.

ii. Next cycle time is calculated by the equation (7.1) as follows

$$c(n+1) = c(n) + 65 * x_{imax}(n) - f(c(n)) \qquad (7.1)$$

The function $f(c(n))$ used in equation (7.1) is defined as in equation (7.2). $x_{imax}(n)$ is the highest degree of saturation in actually indexed cycle; f_{max}, f_{min}, c_2, c_1 are default constant values which are used as 55. 40, 180, 70 respectively in this study,

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$$f(c(n)) = f_{min} - (c(n) - c_1) * ((f_{max} - f_{min}) / (c_2 - c_1)) \tag{7.2}$$

if $c(n) < c_1$ then $f(c(n)) = f_{min}$,

if $c(n) > c_2$ then $f(c(n)) = f_{max}$

iii. The calculated result of the next cycle time is compared with the cycle time that is in use and the new cycle time is defined as follow (Δc = 5 sec. has been accepted as an default value in this study):

if $c(n+1) - c(n) \geq \Delta c$ then $c(n+1) = c(n) + \Delta c$

if $c(n+1) - c(n) \leq -\Delta c$ then $c(n+1) = c(n) - \Delta c$

if $-\Delta c < (c(n+1) - c(n)) < \Delta c$ then $c(n+1) = c(n)$

iv. The time calculated for the next cycle is compared with the minimum and maximum cycle times,

if $c(n+1) \leq c_{min}$ then $c(n+1) = c_{min}$

if $c(n+1) \geq c_{max}$ then $c(n+1) = c_{max}$

v. Actual next cycle time is calculated by adding inter-green times to calculated cycle time value :

$$CT(n+1) = c(n+1) + 2 * (IGT + BIGT) \tag{7.3}$$

IGT and *BIGT* are inter-green time and barrier inter-green time respectively as shown in Figure 2. In this study these values have been accepted as 3 second constant default values.

8- Green Splits Optimization Algorithm

Calculation algorithm which optimize the green splits has been established as follows:

i. For each flow the average degrees of saturation value is calculated: $x_i(n)$.

ii. For each flow the effective phase usage ratio is calculated: $\rho_i(n)$

$$u_i(n) = GT_i(n) / c(n), \qquad \rho_i(n) = x_i(n) * u_i(n) = GT'_i(n) / c(n) \tag{8.1}$$

Here $c(n)$ represents the cycle time at n th cycle; for i'th flow at nth cycle $x_{i(n)}$ represents the average degree of saturation, $u_{i(n)}$ the phase usage ratio. $\rho_{i(n)}$ the effective phase usage ratio.

v. For each flow forecasted, the effective phase usage ratio is calculated for the next cycle:

$$\rho_i(n+1) = \alpha * \rho_i(n-4) + \beta * \rho_i(n-3) + \gamma * \rho_i(n-2) + \delta * \rho_i(n-1) + \theta * \rho_i(n)$$

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Here: $\alpha, \beta, \gamma, \delta, \theta < 1$ represent weighting factors ($\alpha + \beta + \gamma + \delta + \theta = 1.0$). $\rho_i(n-j)$ the effective phase usage ratio for i'th flow at $(n-j)$ th cycle, $\rho_i(n-1)$ the forecasted effective phase usage ratio for next cycle.

vi. For the next cycle t_{B1} and t_{B2} barrier duration's which are total green times for the flows in the east-west and south-north directions and green split times for all different flows are calculated as follows:

i. t_{B1} and t_{B2} barrier calculations:

$$\rho_{C1} = \rho_1(n+1) + \rho_2(n+1)$$
$$\rho_{C2} = \rho_3(n+1) + \rho_4(n+1)$$
$$\rho_{C3} = \rho_5(n+1) + \rho_6(n+1)$$
$$\rho_{C4} = \rho_7(n+1) + \rho_8(n+1)$$
$$\rho_{m1} = \max(\rho_{C1}, \rho_{C3})$$
$$\rho_{m2} = \max(\rho_{C2}, \rho_{C4})$$
$$t_{B1} = c(n+1) * \rho_{m1} / (\rho_{m1} + \rho_{m2}), \quad BT1 = t_{B1} + IGT + BIGT$$
$$t_{B2} = c(n+1) * \rho_{m2} / (\rho_{m1} + \rho_{m2}), \quad BT2 = t_{B2} + IGT + BIGT$$

ii. Minimum and maximum t_{B1} and t_{B2} are inspection:

$$t_{B1min} = \max((GT1_{min} + GT2_{min}), (GT5_{min} + GT6_{min}))$$
$$t_{B2min} = \max((GT3_{min} + GT4_{min}), (GT7_{min} + GT8_{min}))$$
$$t_{B1max} = \min((GT1_{max} + GT2_{max}), (GT5_{max} + GT6_{max}))$$
$$t_{B2max} = \min((GT3_{max} + GT4_{max}), (GT7_{max} + GT8_{max}))$$
$$\text{if} \quad t_{B1} < t_{B1min} \quad \text{then,} \quad t_{B1} = t_{B1min}, \; t_{B2} = c(n+1) - t_{B1min}$$
$$\text{if} \quad t_{B2} < t_{B2min} \quad \text{then,} \quad t_{B2} = t_{B2min}, \; t_{B1} = c(n+1) - t_{B2min}$$
$$\text{if} \quad t_{B1} > t_{B1max} \quad \text{then,} \quad t_{B1} = t_{B1max}, \; t_{B2} = c(n+1) - t_{B1max}$$
$$\text{if} \quad t_{B2} > t_{B2max} \quad \text{then,} \quad t_{B2} = t_{B2max}, \; t_{B1} = c(n+1) - t_{B2max}$$

iii. Calculation green split times for each flow:

$$GT1(n+1) = t_{B1} * \rho_1(n+1) / \rho_{m1}$$
$$GT2(n+1) = t_{B1} * \rho_2(n+1) / \rho_{m1}$$
$$GT3(n+1) = t_{B2} * \rho_3(n+1) / \rho_{m2}$$
$$GT4(n+1) = t_{B2} * \rho_4(n+1) / \rho_{m2}$$
$$GT5(n+1) = t_{B1} * \rho_5(n+1) / \rho_{m1}$$
$$GT6(n+1) = t_{B1} * \rho_6(n+1) / \rho_{m1}$$
$$GT7(n+1) = t_{B2} * \rho_7(n+1) / \rho_{m2}$$
$$GT8(n+1) = t_{B2} * \rho_8(n+1) / \rho_{m2}$$

9- Simulation Results

Optimization algorithms introduced above have been transferred to VISSIM simulation environment by using VAP programming language commands in order to optimize the critical intersection model. VISSIM is a microscopic simulation program which simulates the urban traffic that depends on psycho-physical driver behaviors. Fixed time signal control policies and vehicle actuated programs can be tested with VISSIM. Also, various on-line and off-line analysis can be made under the previously determined constraints. Simulation process is run as outlined in Figure 4 (VISSIM User Manual, 1997).

In this study, critical intersection model constructed in VISSIM, has been operated first in VAP mode, second in fixed time mode under the same conditions for over 4 hours. Through the simulation, time dependent vehicle inputs and relative distribution of flows has been chosen as in Table 1.

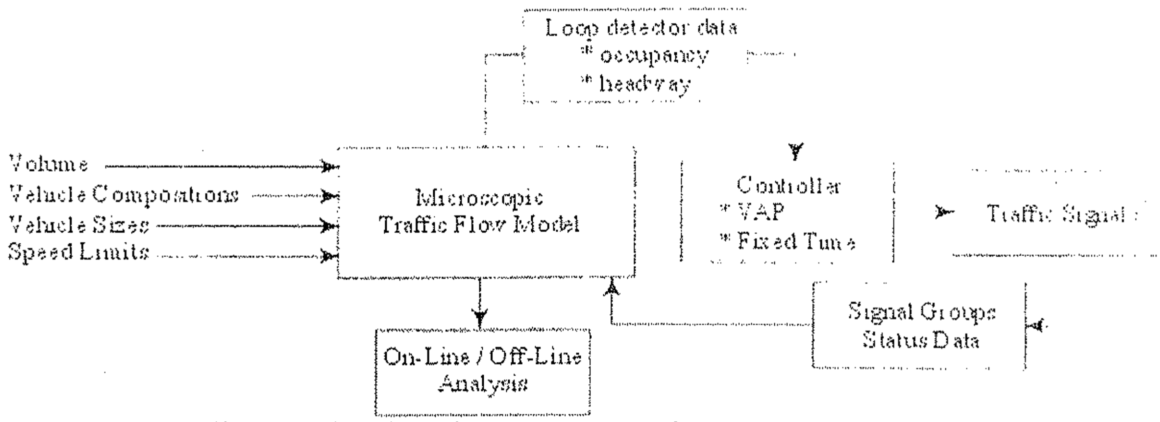

Figure 4- *Flow chart about running a simulation process in VISSIM*

In VAP mode operation testing results outlined in two different graphics in Figure 5 . First graphic shows the realized cycle time variations and the two of the green split time variations (GT1 and GT2). The second graphic shows the realized maximum degree of saturation which corresponds the intersection degree of saturation (MXS = X) and arithmetic average of degrees of saturation that occurs according to all flows.

Table 1. *Vehicle inputs and relative distribution of flows through the simulation (relative flows have been identified as left turning flow, through flow and right turning flow respectively)*

simulation second	0-3600	3601-7200	7201-10800	10801-14400	14401-18000
Vehicle Input from West	1200	1000	800	600	400
Rel. Flow dist.	1-5-1	1-5-1	1-5-1	1-5-1	1-5-1
Vehicle Input from North	1300	1100	900	700	500
Rel. Flow dist.	1-4-2	1-4-2	1-4-2	1-4-2	1-4-2
Vehicle Input from East	400	500	600	700	800
Rel. Flow dist.	1-2-1	1-2-1	1-2-1	1-2-1	1-2-1
Vehicle Input from South	600	700	800	700	600
Rel. Flow dist.	1-2-1	1-2-1	1-2-1	1-2-1	1-2-1

Then, by using VAP mode simulation results, an average cycle time and green splits have been established to be used in fixed time mode simulations. These values are 122 seconds for cycle time; 0.15 for left turning flows and 0.35 for through flows plus right turning flows.

By using these values fixed time mode simulation has been done under the same conditions as in VAP control mode. Fixed time mode simulation results outlined in Figure 6 are in the same format with Figure 5.

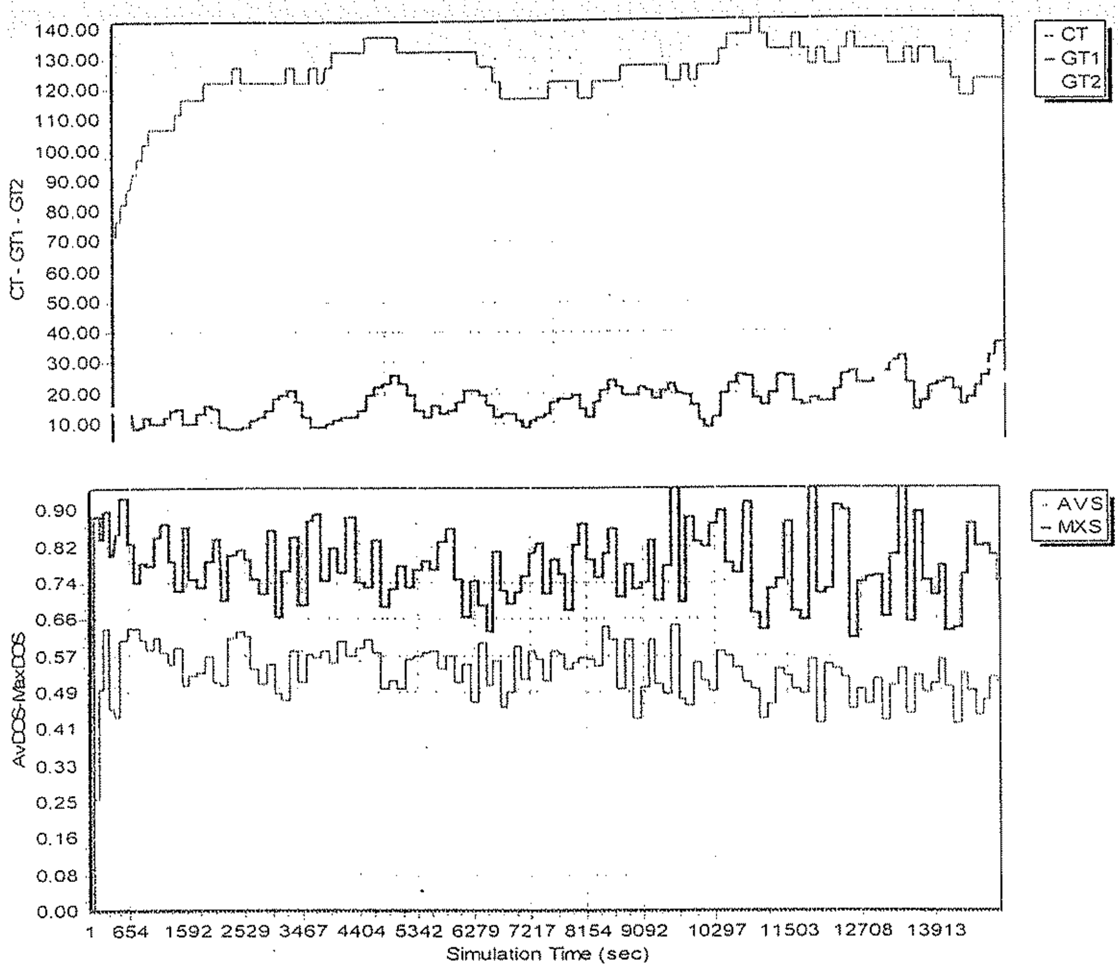

Figure5- *VAP mode simulation results: CT, GT1, GT2, X = MXS, average X = AVS.*

According to these results:

*Realized average degree of saturation values exceed the value of 0.9 (practical degree of saturation value) only in the 6 of the cycle indexes in VAP mode and 15 of the cycle indexes in fixed time mode through the simulation,

*Realized average degree of saturation values exceed the value of 0.8 in the 35 of the cycle indexes in VAP mode and 64 of the cycle indexes in fixed time mode through the simulation.

*The arithmetic averages of degrees of saturation (AVS) that occurs according to the degrees of saturation of all different flows are accessed. According to this accession, it's obvious that the AVS values vary absolutely between 0.42 – 0.64 in VAP mode and 0.35 – 0.72 in fixed time mode. According to the variation difference of average AVSs, the values diverge between 0.45 – 0.60 in VAP mode and 0.50 – 0.65 in fixed time mode through the simulation.

All these results show that under the various saturated traffic compositions, the variations of average degrees of saturation of total flows can be smoothened and average degree of saturation of intersection can be maintained near the practical degree of saturation (0.7-0.9) which corresponds to optimum volume and performance of the critical intersections.

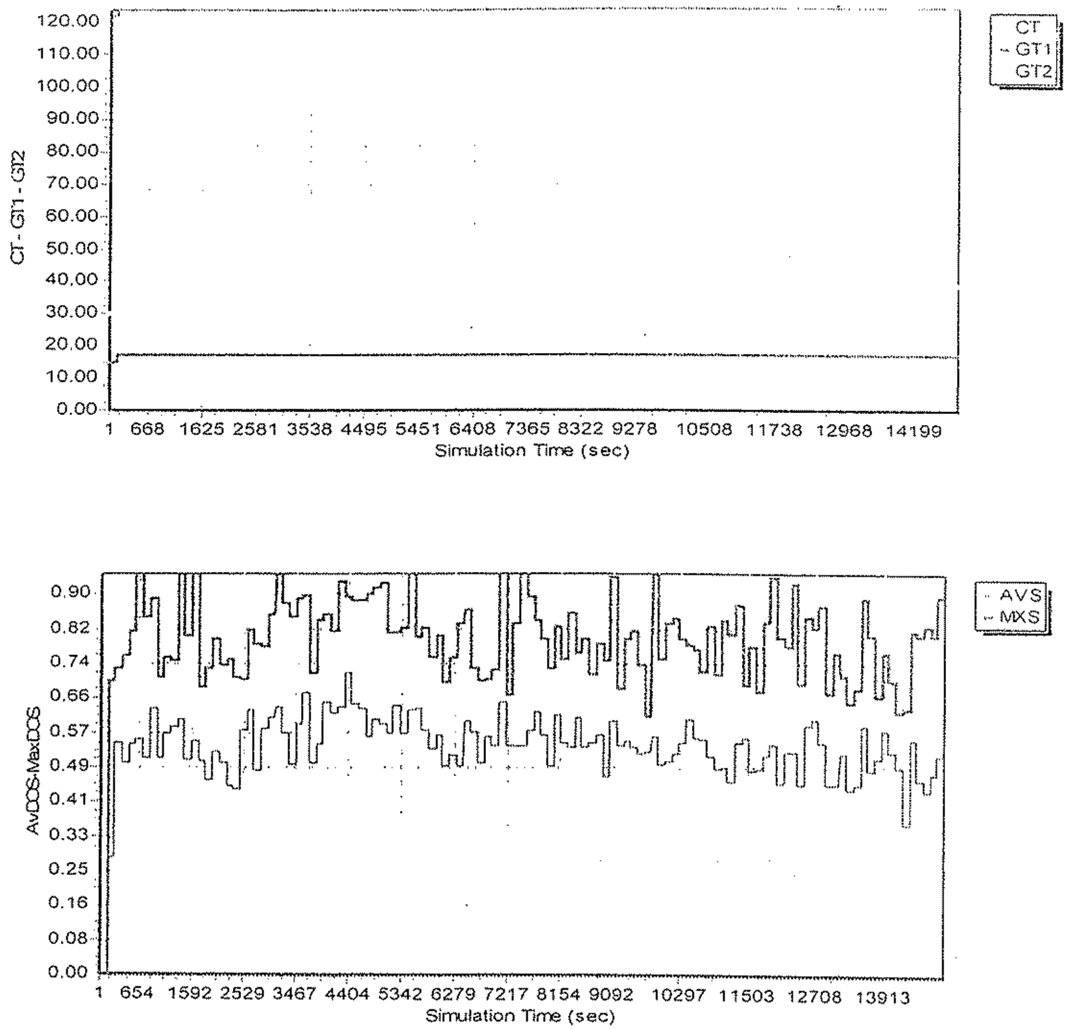

Figure6- *Fixed time mode simulation results: CT, GT1, GT2, X = MXS, average X = AVS.*

10-Conclusion

In this study simulation experiments realized for optimization of isolated intersections. Also similar studies can be planned in order to simulate the optimization of coordinated signals in a sub area. In this frame new simulation based studies are being planned.

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