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Stochastic Optimization of Signal Timings for Improving Traffic Flow at Road Intersection

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ABSTRACT

In order to achieve the comfort, safety and to organize the traffic flow in an organized manner, traffic signal timings play a vital role. The average delay incurred by vehicles at signalized intersections is commonly used as a measure for quantifying intersection performance, both in design and evaluation procedures. In appropriate signal timings not only cause the delay of travel time but also increase emissions and fuel consumption. Thus it is important to investigate the practice of signal optimization methodology to ensure the timing plan for improving the system performance. Signal optimization helps to control the stopping time at the traffic signals which ultimately leads to the reduction of delays. In order to optimize the signal timings, the investigations can be conducted either in the field or by using a reliable simulation tool. Several scientific interventions revealed that simulation tools likeTRANSYT-7F and SYNCHRO,VISSIM,CORSIM, etc. helps to optimize the signal timings and predicts the scenario in accurate manner. Due to the risk and time requirements of the field testing,simulation tools are being widely used.Calibration parameters like traffic volume, vehicle speed, type of vehicles, driver behavioral characteristics etc. are identified using sensitivity analysis, and the optimum values for these parameters can be obtained by minimizing the error between the simulated and field delay using genetic algorithm.However,simulation models can be properly calculated and validated so that the model output can be trusted. This thesis deals with the stochastic way of optimizing the signal timings using the simulation tool VISSIM for Indian scenario. It simulates the traffic of any road network and compares the results that are obtained in the field. Later, by doing the sensitive analysis one can stochastically or deterministically design the capacity of an intersection, signal timings etc. A microscopic, stochastic model VISSIM is chosen for this study because it provides application programming interface(API).

I. INTRODUCTION

This is very evident in times of peak traffic flow. Traffic signal management is one of the fastest methods to achieve traffic congestion improvements. While building new roads can take years, a new traffic signal plan can be implemented in a matter of weeks. There are four control parameters for traffic signal management, they are: A.)**Offset**: Time between cycle starts of different signals;

B.)**Stage specification**: Outlines what options (go straight, turn left, etc.) a vehicle has at any given time at each intersection;

C.)Cycle time: Time it take a signal to progress through all stages

D.)Split: Portion of a cycle that the signal is green for each direction

VISSIM is a microscopic, time step, and behavior-based simulation model. VISSIM uses the psychophysical driver behavior model developed by Wiedemann in 1974. The basic concept of this model is that the driver of a faster moving vehicle starts to decelerate as he or she reaches his or her individual perception threshold to a slower moving vehicle. In the process of simulation, since the drivers of faster moving vehicles cannot exactly determine the vehicle speed, speed of such vehicles will fall below the speed of slower moving vehicles until the driver starts to accelerate the speed again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration.

A stochastic distribution of speed and spacing thresholds replicates individual driver's behavioural characteristics. The test site was coded in VISSIM software environment using the field collected data. The VISSIM model consists of two components: a simulator and signal state generator. The simulator is responsible for generating traffic for the graphically built network.

As a case study, an existing 4 lane signaling system was considered over the study location. An aerial photograph of the study area was imported into the simulator. The road network can be drawn using links & connectors. The network was then "digitized" over the aerial photograph, and attributes from the data collection were applied (e.g., lane widths, speed zones, detector locations). Although links are used in the simulator, VISSIM does not have a traditional node structure. This link-based structure allows flexibility to control traffic operation (e.g., yield conditions) and vehicle paths within an intersection.

The signal state generator is separate from the simulator and is where signal logic presides. Signal control logic is input here for each intersection as VAP (vehicle actuated programming) files. In these VAP files, signal characteristics are entered for the actuated signals including phase sequences, minimum green times, force-offs, and gap out times. The signal state generator reads detector information from the simulator at every time step. The signal state generator decides the signal display during a time step based on the detector information. Stochastic or in deterministic way of optimizing signals involves the following methodology:

As the optimization involves in decreasing the unwanted delays, field delays have to be collected and then those values have to be validated by simulating the similar traffic conditions in the micro simulator. Measurements for stopped delay as well as deceleration and acceleration delays were obtained in the field by tracing individual vehicle trajectories between a point at 235 m upstream of the intersection stop line and a point at 120 m downstream of the intersection. The roadway between these two points was referred in the current study as the "system". The part of the system upstream of the intersection was divided into seven sections formed by eight control stations or screen lines, while the part of system downstream of the stop line was divided into four sections. It allows for calculating the speed and acceleration rate of vehicles at any point in the system.

Measured delays of vehicles that stopped and vehicles that did not stop were analyzed separately and then combined to give delays for the average vehicle. The calibrated VISSIM simulation model yields mean absolute errors of 17.6% and 20.7% for four-lane and six-lane streets, respectively. After validating the software, sensitive analysis was carried out by changing different parameters in the field and observing the changes in the delays. Delays can be evaluated by applying travel time sections to the links of the network. For the accuracy in optimizing the performance of the intersection, queue lengths can also be calculated by applying queue counters to the links of the network. Signals are said to be optimized when the delay obtained with the change of one parameter should be less than the delay obtained from the other sensitive parameters. The presented approach can be effectively applied to optimize the signal timings over various signalized intersections for reducing the travel time as well as air pollution.

II. OBJECTIVES

a.) Optimize the selected signalized intersection considering stochastic variability, and evaluate its performance using microscopic simulation software called VISSIM.

b.) Calculate field delays and compare them with simulated values to validate the selected simulation software.

c.) Identify the sensitive parameters by doing sensitive analysis and calculation of delays using sensitive parameters.

III. LITERATURE REVIEW

Vehicular delay is an excellent tool for evaluating the better operation of signalized intersections. **Ragab M. Mousa (2002)** suggests that the delays due to vehicles that didn't stopped comprises only about 7% of the total delay and it can be neglected, while delay estimated from stopped vehicles is about 93% of the total intersection delay. After modeling the relationship between delay components showed a ratio of about 2.0 between the total delay and stopped delay, a ratio that is significantly higher than the 1.3 factor adopted in the 1994 Highway Capacity Manual.

The approach delay was estimated at about 85% of the total delay, indicating a significant percentage of total delay that takes place downstream of the intersection stop line. Consideration of vehicular delay at signalized intersections also improves the accuracy of equilibrium flows obtained from traffic assignment models. **Ehsan Mazloumi, Sara Moridpour, and Hassan Mohsenian (2010)** states that delay depends on driver's behavior and specific traffic culture in each country in addition to physical specifications of the intersection, signal timing, and traffic volume and its composition.

In urban areas situating bus stops will also decide the delays at the nearby intersection. For a single-lane approach, where the overtaking of a stopped bus at the bus stop is prohibited, the setup of such a bus stop would significantly affect the delay incurred by road users. **S.C.Wong, Hai yang, W.S.Au Yeung, S.L.Cheuk and M.K.Lo (1998)** suggested that the delay in such situations depends on a number of factors, such as the distance between bus stop and stop line, traffic and bus flows, dwell time of buses and signal settings. Researchers developed a simulation model for estimating the delay on an approach to a signal-controlled intersection with a bus stop upstream.

IV. METHODOLOGY

Stochastic way of optimizing the signals considers delay as an objective function. Optimization of signals involves decreasing the unwanted delays at an intersection. So it is necessary to calculate the field delays manually using the methods suggested by highway capacity manual (HCM) and then by inputting the field values in the software simulated delays are calculated. A brief methodology is proposed for the optimization of signal timings is presented in flow chart below.

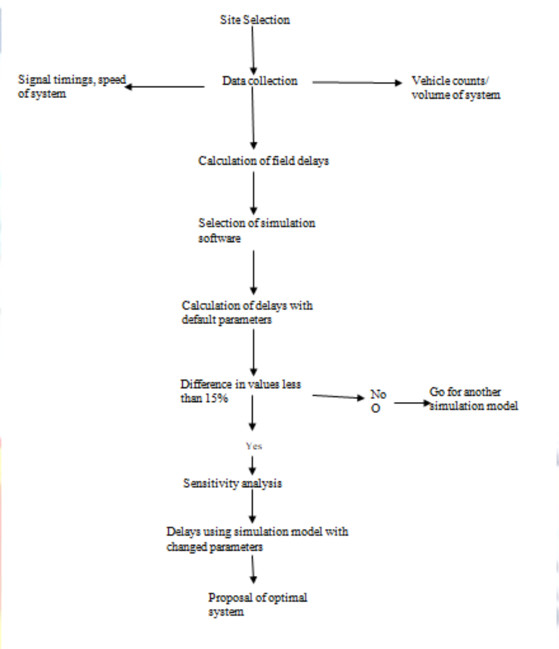

Fig.1 *Procedure for Optimization Of Signal Timings*

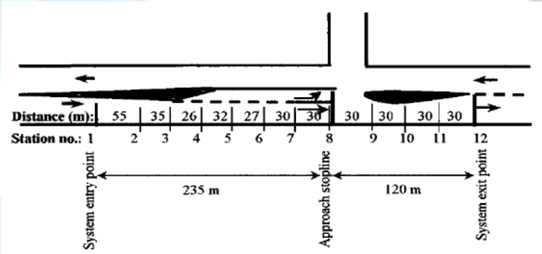

Fig.2 *Screen Lines Used For Speed Data Collection.*

Highway Capacity Manual (HCM) has proposed a technique to calculate the field delays. The above represents the schematic diagram for the measurement of field delays. Measurements for stopped delay as well as deceleration and acceleration delays were obtained in the field by tracing individual vehicle trajectories between a point at 235 m upstream of the intersection stop line and a point at 120 m downstream of the intersection.

The roadway between these two points was referred to in the current study as the "system." Tracing vehicles in the system was achieved by measuring the vehicle crossing times at 12 screen lines. The above figure depicts the system and the screen lines, where the first station or screen line represents the system entry point and is used as a global reference for all distances and times measured in the system.

Station 8 is typically the stop line at the traffic signal, and Station 12 is the system exit point and is selected at the site where all vehicles have achieved a speed closer to the average speed at the system entry point.

The part of the system upstream of the intersection was divided into seven sections formed by eight control stations or screen lines while the part of system downstream of the stop line was divided into four sections.

The roadway between these two points was referred to in the current study as the "system." Tracing vehicles in the system was achieved by measuring the vehicle crossing times at 12 screen lines. Schematic space-time diagram depicting delays at signalized intersections is shown in figure below.

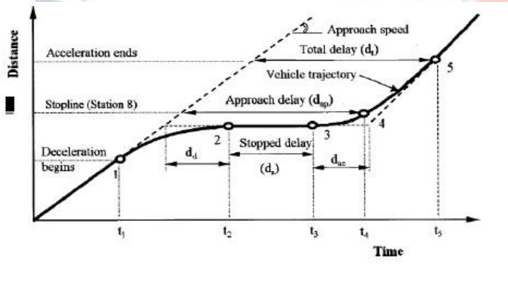

Fig.3 *Graph between Time and Distance Giving Delays.*

V.CASE STUDY

The methodology designed is applied to a case study of Market Area, Guntur. It is a 4 road intersection of all main roads. It is situated between two minor signalized intersections. It is one of the busiest intersections in Guntur. Two bus stops are located at a distance of 100 m from the signal point on either side of the road. The aerial photograph and simulation screen shot of the site is shown in figures below.

Fig.4 Aerial Photograph Of Market Area,Guntur

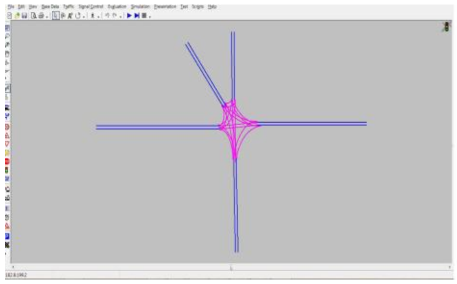

Fig.5 Centre Line View Of Vissim Simulation Screen Shot

Table 1: Geometrical Characteristics Of Selected Site

No. of links	5
No. of connectors	20
No. of lanes for each link	2
Width of lane	3.5 m

Table 2: Volume Counts Of Selected Site

S.No	Date	Volume	Peak hour factor	Design volume
1	25/12/18	1930	0.778	2480
2	26/12/18	1860	0.788	2360
3	27/12/18	1970	0.769	2561
4	28/12/18	1640	0.745	2200

Table 3: Driver Charecteristics Of Selected Site

Average speed of a vehicle	31 kmph
Min headway maintained	5 m
Min gap time	3 sec

Table 4: Signal Characteristics of Selected Site

Total cycle time	135 sec
Red time	105 sec
Green time	25 sec
Amber time	5 sec

Table 5: Field Delay Values of Selected Site

S.NO	First point	Second point		Third point		Fourth point		Delay (sec)			Total Delay (sec)
	Speed (kmph)	Time (sec)	Speed (kmph)	Time (sec)	Speed (kmph)	Time (sec)	Speed (kmph)	Dd	Ds	Dac	
1	31	7	29	12	14	9	42	5	105	4	114
2	25	9	23	14	16	8	43	6	105	5	117
3	32	7	30	13	17	17	21	7	105	4	116
4	27	8	26	14	16	9	42	6	105	4	115
5	39	6	35	13	17	14	25	8	105	6	119
6	35	5	26	7	22	14	26	3	105	3	111
7	32	5	26	8	19	15	24	3	105	3	111
8	33	5	26	7	22	15	25	4	105	5	114
9	30	5	26	6	25	15	24	3	105	4	112
10	40	5	26	8	19	14	27	4	105	6	114
11	25	9	24	11	21	12	29	3	105	4	112
12	30	8	27	10	23	12	30	2	105	3	110
13	24	10	22	12	20	14	26	5	105	7	117
14	34	6	27	7	24	12	30	4	105	4	113
15	42	5	32	7	24	12	31	4	105	3	112
16	24	8	20	9	19	16	22	4	105	5	114
17	26	7	23	8	21	16	23	2	105	3	110
18	27	8	20	9	19	14	24	5	105	4	114
											Avg= 114sec

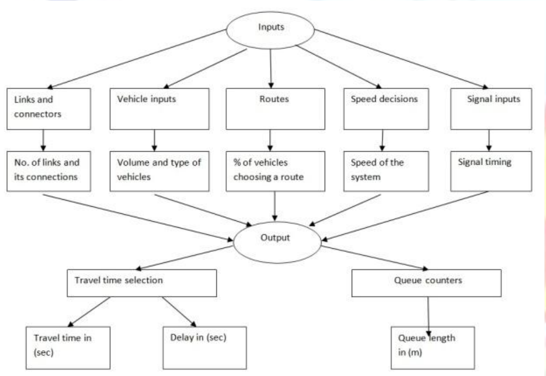

Fig.6 Inputs for VISSIM

VI. RESULTS

Simulation had been done with the default parameters of VISSIM and with the input of field data. First objective of the simulation run is to check whether the software considered is valid or not. To validate the software, field delays are compared with the first simulation run i.e. using default parameters of the software and the obtained results holds good if converge up to 85% or more . The following table shows the default parameters of the VISSIM.

Table 6: Default Parameters Of Vissim

Link data	No. of lanes on each link=2
	Behavior
	Lane width= 3.5m
	Lane change= 200m back
Vehicle types	Car, HGV, Bus, Pedestrian,
Signal control	Amber time= 3sec
Car following	Wiedemann 74
Driving Behavior	Look ahead distance=
	Look back
	Max deceleration=-4m/sec^2
	Min headway= 0.5m
	Max longitudinal
	Behavior at Amber= Go as

Table 7: Delay Values For Different Green Times With Field Data

Green Time(Sec)	Delays for simulation
34	149.90
33	144.60
32	140.90
31	130.86
30	128.80
29	122.28
28	120.96
27	116.18
26	112.76
25	108.00
24	100.38
23	93.60
22	89.20
21	81.78
20	76.71

Field delays for the green time of 25 is 114, where as the simulated delays for the green time of 25 is 108 which has a difference of less than 15% which shows that we can proceed with the software for the further analysis.

Table 8: Driver behavioral parameters used in Sensitive analysis

Link data	No. of lanes on each link=2
	Behavior type=urban(motorized)
	Lane width= 3.5m
	Lane change= 200m back
Vehicle types	Car, Bus, Pedestrian, Bike
Signal control	Amber time= 3sec
Car following model	Wiedemann 74
Driving Behavior	Look ahead distance=300 m(max)
	Look back distance=150m(max)
	Max deceleration=-3m/sec^2
	Min headway= 0.5m
	Max longitudinal speed=4km/hr and behavior at amber = stop as red

Table 6.4: Delay and Queue length values for different Green times with sensitive parameters

S.NO	Green time (sec)	Simulation results with change of different sensitive parameters							
		Speed variation		Vehicular change		Volume change		Driver behavior Change	
		Delay (sec)	Queue Length (m)	Delay (Sec)	Queue Length (m)	Delay (sec)	Queue Length (m)	Delay (sec)	Queue Length (m)
1	34	134.24	86.00	147.16	81.33	135.9	75.33	106.5	87.33
2	33	124.80	82.33	146.10	86.00	126.37	74.67	92.43	87.33
3	32	122.63	82.67	136.36	87.00	122.03	69.33	94.00	85.67
4	31	116.44	81.67	133.93	85.33	119.90	71.00	90.03	82.33
5	30	110.30	82.33	134.40	83.67	114.00	68.00	85.70	84.33
6	29	108.42	80.00	124.16	83.00	113.17	65.00	85.70	83.67
7	28	102.61	80.33	111.46	81.00	107.73	57.67	80.10	83.67
8	27	92.93	78.67	115.53	81.33	101.73	62.00	74.26	75.67
9	26	88.73	77.00	109.80	79.33	97.73	61.00	75.50	81.66
10	25	86.00	78.00	105.43	79.67	93.27	63.33	76.40	78.33
11	24	83.21	73.00	100.60	77.67	85.73	60.33	71.63	79.33
12	23	78.59	74.00	92.10	77.33	79.76	56.33	65.70	80.00
13	22	75.72	71.33	88.10	78.00	77.23	53.33	75.00	73.33
14	21	69.91	68.67	79.93	72.67	69.83	51.00	72.56	72.33
15	20	65.17	65.67	76.13	81.33	67.53	50.33	67.46	71.67

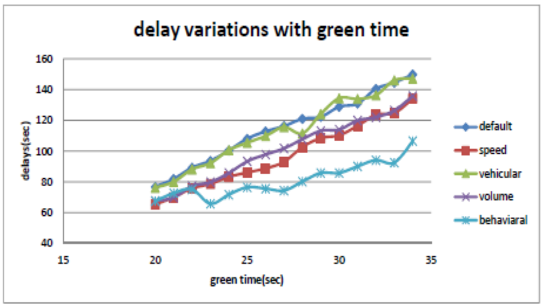

Fig.7 Variation Of Delays For Different Green Times With Sensitive Parameters

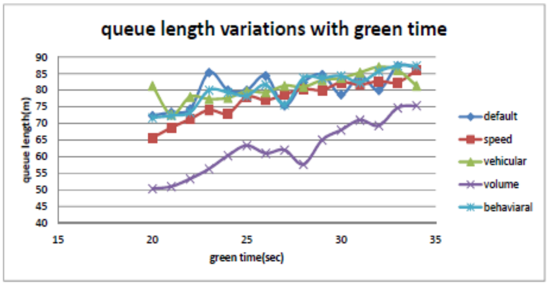

Fig.8 Variation Of Queue Lenghts For Different Green Times With Sensitive Parameters

VII. CONCLUSIONS

1.) System delays are reduced to 29% at the same cycle time as that of field by considering driving behavior as a sensitive parameter. It is therefore concluded the proposed methodology for setting timing plans works well in improving performance.

2.) That 29% of reduction in delays will save about 8419 hours per year for all vehicles in system during the peak hours. Delay savings were calculated by taking the difference of average delay per vehicle for the base and field conditions.

3.) From the above results, it is clear that the delay values over a green time of 27, 26 and 25 do not differ much. So the proposed optimal signal timings for studied area are the cycle length of 135, 130 and 125 for the respective green timings.

4.) As discussed earlier, driving behavior has a huge impact on delays that are occurring at intersections. So in addition to the better signal timings, driving behavior at signal points should be maintained better.

5.) Driving behavior involves better headway maintenance, acceleration and deceleration at signal points and behavior at amber signals (whether go as green or stop as red).

6.) Better maintenance of headway between the vehicles may also reduce accidents at the signal point or at left turn lanes

7.) Vehicles will consume less amount of fuel if they don't have to wait at signalized intersections for a longer time. It also helps in reducing annual fuel consumption cost and environmental pollution.

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