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PERFORMANCE EVALUATION OF A FOUR-LEGGED INTERSECTION USING MICROSCOPIC SIMULATION MODEL

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Abstract: Traffic congestion is a widely spreading problem throughout the world. The gap between traffic demand and supply is increasing day by day that makes junctions, a traffic congestion spot. In this study, a four legged intersection has been evaluated that suffers from high congestion. The traffic within the study area is mostly heterogeneous with non-lane based flow. A microscopic simulation model has been used to assess the performance of the intersection. Using VISSIM, the on-field condition is replicated to observe the behaviour of the prevailing system. Several traffic data are collected from the study area. Then the simulation model is calibrated with the field data and validated with another day's field data, signifies that the developed model clearly mimics the reality. The driving behaviour parameters are tuned to replicate the lane indiscipline existing in the field. The model is analyzed for several conditions such as existing two phase, modified two phase and four phase signal control. It is found that travel time for modified two-phase is more favourable than the existing two-phase signal. Moreover, delay result is more conducive in modified two-phase system. It is to be noted that the four-phase signal produces maximum queue length. The signal design modification can be a great solution to improve the existing congestion condition prevailing in the studied intersection. The strategy used in the model can be incorporated for the improvement of any intersection adjusting the calibration standards. Increase of efficiency of intersections suffering congestion will lead to a better urban traffic system.

1 Introduction

On a typical four-leg intersection, one out of two intersecting roads has the higher traffic volume. This roadway is referred to as the major or arterial road. The second roadway, which services the lower traffic volume, is referred to as the minor or collector road. When the volume on either road nears capacity, queues begin to form, raising the potential for unsafe driving manoeuvres. For this reason, improving safety and operational efficiency at intersections on urban road intersections remain a constant goal (Naghawi 2014). Intersections are usually considered as the critical points within the network and the evaluation of their performance provides valuable understanding and useful indication about the performance of the system (Sunil 2013).

Signalised intersections are one of the key locations in any transportation network, hence improper planning of the intersection affects the performance and productivity of the whole road network. A thorough analysis has to be made to utilise the signalised intersections effectively. The analytical approach has the limitation of underlying assumption of homogeneity, which is having high variations of traffic characteristics when compared with a mixed traffic condition. Simulation models on the other hand, follow the dynamic nature of the traffic system and give a continuous view of the state of the traffic system over time. This characteristic of simulation model is an advantage over analytical models, since it gives more insight to what is happening in the system in detail. Hence, researchers concentrated on appropriate modelling technique through simulation, which is emerged as the most powerful and acceptable solution searching tool (Sheela 2014).

Dhaka is the capital of Bangladesh, one of the mega cities in the world. 'Banglamotor' of Dhaka is a busy four legged intersection during the peak hours. Non-lane based flow predominates and traffic is mixed with both motorized and NMV's in the minor road while only motorized vehicle ply on major road due to the restriction imposed by the road authority. This intersection need to be analyzed for improvement in terms of various traffic characteristics. In this study this intersection is modeled with microscopic simulation software. Out of numerous parameters, signal timing and phasing is modified to understand the traffic properties, how it changes and improves the present condition. The improvement will help the overall increase in performance of the urban intersection that will eventually help in building a congestion free society.

Figure 1: Four-legged busy intersection named 'Banglamotor' of megacity Dhaka

2 Literature Review

Traffic micro-simulation models are widely used to evaluate the benefits and limitations of traffic operation alternatives. Traffic simulation models are mainly classified as microscopic and macroscopic. Models that simulate individual vehicles at small time intervals are termed as microscopic, while models that aggregate traffic flow are termed as macroscopic. Microscopic simulation has been used for a long time to simulate project scale cases such as intersection design. Thus computer simulation is a valuable tool for the analysis and design of complex transportation systems.

Simulation models may be classified as being static or dynamic, deterministic or stochastic and discrete or continuous. (Keller and Saklas 1984) developed a procedure to estimate Passenger Car Equivalent (PCE) values using simulation model. (Banks et al. 2000) mentioned the choice of whether to use a discrete or continuous simulation model is a function of the characteristics of the system and the objectives of the study. (Hossain 2001) used micro simulation technique to model traffic operations at signalised intersections. (Arasan and Koshy 2005) developed a simulation model for urban roads. (Mallikarjuna and Rao 2006) developed a Cellular Automata based simulation model to estimate PCU. (Arasan and Krishnamurthy 2008) conducted a study on the effect of traffic volume and road width on PCU values of vehicles using Microscopic simulation. (Arasan and Vedagiri 2006) applied the simulation model to estimate the saturation flow rate of heterogeneous traffic. (Gowri and Sivanandan 2008) developed a simulation model and examined the effects of left turn channelization on vehicle waiting times. (Arasan and Arkatkar 2010) and (Arasan and Dhivya 2010) also have developed micro simulation models for midblock sections. (Radhakrishnan and Mathew 2011) developed a traffic simulation model integrating the concepts of cellular automata. Thus microscopic simulation models are used in recent times for numerous purposes. However, the effect of signal time and signal phase modification can alter a lot of changes to traffic properties of an intersection which has not been extensively studied.

Traffic signals are one of the most effective active controls of traffic. The advantage of traffic signal includes an orderly movement of traffic and increased capacity of the intersection. However, the disadvantages of the signalized intersection are large stopped delays and complexity in both design and implementation. For a signalized section, signal phase is the part of a cycle allocated to a stream or a combination of two or more streams having the right of way simultaneously. Traffic fixed time controller signal may be of different phasing options. Figure 2 illustrates the conventional signal phase systems. This study discuss various alternatives among signal phase and timing modification of fixed time controller and their comparative effects on traffic condition such as congestion.

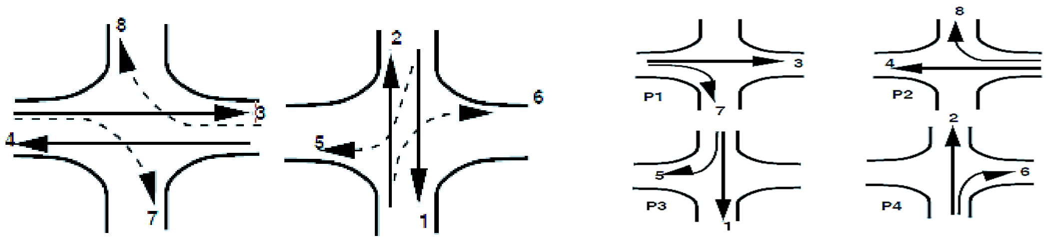

Figure 2: Traffic movements in two phase and four phase fixed-time controller signal system respectively (Mathew 2017)

3 Methodology

The efficiency of a transportation network depends on the performance characteristics of its various components. To improve the efficiency, proper planning and design of various facilities have to be implemented (Sheela 2014). This paper focuses on simulating traffic movements at signalised intersection by developing a micro simulation model using various signal phase system to improve the intersection performance.

The studied intersection is modeled with micro simulation software named ‘VISSIM’ version 5.40. As micro simulation encounters with individual track of vehicles, distance and time headway, lane changing behaviour, car following model, so extensive data are required. Basic data collected are the geometry of the intersection, number of lanes, lane width, median width, channel dimensions, traffic volume, directional count, signal phasing, cycle times, green, red and amber times, saturation flow, traffic composition, queue length, travel time, speed of vehicles etc. The traditionally simplest approach for conducting manual count is to record each observed vehicle with a tick mark in a tally sheet that has been used in this study. Indirect method of manual counting, the video camera is also utilized for the purpose of verifying the collected data (Manual of Transportation Engineering Studies 2010) as presented in Figure 3.

Figure 3: Manual method (direct and indirect both) is used to collect traffic volume and intersection counts

With these data input, the intersection model is generated. The network generation process includes importing and scaling overlay image after fixing units, determining driver behavior parameters, individual link behavior fixing, link and connector generation, determination of vehicle types and classes, vehicle composition selection, vehicle input in all the arrival points of the network, routing for various links, conflict area and priority implementation and signal head along with signal program implementation etc. Then, data collection points, travel time sections and queue counters establishments are done where necessary for evaluation purpose.

After the network design completion, the simulation is initiated with random seed value. If the random seed varies, the stochastic functions in VISSIM are assigned a different value sequence and the traffic flow changes. This allows stochastic variations of vehicle arrivals in the network. For meaningful results it is recommended to determine the arithmetic mean based on the results of multiple simulation runs with different random seed settings.

Calibration of the generated model is executed to check whether it replicate the existing situation of the intersection. Calibration is defined as the process of adjusting the parameters used in the model to ensure that it accurately reflects input data. The subsequent process of validation is to run an independent check on the calibrated model. Two sets of observed data are therefore required during the model development process. One is used to calibrate the model by adjusting the parameters to ensure that the output matches observed data and the second is used to verify that the aspects of the performance of the calibrated model are in agreement to the set of observed data (Sykes 2010). It is very significant that the output found for particular traffic parameters combinations are within the calibration target range. Calibration target is shown in Table 1.

Table 1: Calibration target

Criteria and measures	Acceptability targets
Hourly flows, model vs observed	
Individual link flows	
Within 15% for 700 vph < Flow < 2700vph	>85% cases
Within 100 vph for Flow < 700 vph	>85% cases
Within 400 vph for Flow > 2700 vph	>85% cases
Total link flows	
Within 5%	All accepting links
GEH statistic- Individual link flows	
GEH < 5	>85% cases
GEH statistic- Total link flows	
GEH < 4	All accepting links
Travel times, model vs observed	
Journey Times Network	
Within 15% (or 1 minute, if higher)	>85% cases
Visual audits	To analyst's satisfaction
Individual link speeds	
Visually acceptable speed-flow relationship	To analyst's satisfaction
Bottlenecks	
Visually acceptable queuing	To analyst's satisfaction

*Source: FHWA Freeway Model Calibration Criteria (Dion et al. 2012)

After the calibration and validation of the generated model is done, the signal phase and timing is redesigned and modified. The existing model with prevailing two phase signal system is checked for modified two phase and four phase signal system. For phase design, saturation flows at all the approaches and lost times are determined first. Subsequently, the green period of all phases and cycle time are calculated. Various traffic parameters are analyzed according to the changes. Alternatives are compared and discussed whether the modification or measure will be suitable and efficient in terms of performance increase of the Banglamotor intersection.

4 Data Collection

Banglamotor is a four legged intersection where Northbound, Southbound, Westbound and Eastbound roads are labelled as SAARC Foara road, Shahbag road, Link road and New Iskaton road respectively. East and Westbound roads have three lanes while South and Northbound roads having four lanes (Figure 4). It is to be mentioned that Eastbound road has a dedicated left turning lane. North and Southbound roads carrying larger traffic flow hence considered as major road arterial.

Figure 4: Geometry of Link road (Westbound), New Iskaton road (Eastbound), Shahbag road (Southbound) and SAARC Foara road (Northbound)

Typical data for the vehicle count for peak hour on a working day along with vehicle composition is shown in Table 2 for the Shahbag road. Table 3 represents the Passenger Car Equivalent (PCE) values which are used to calculate total volume in terms of PCE.

Table 2: Vehicle count for Shahbag road (Southbound)

Movement	Motorcycle	Bike	Car/Jeep/ Micro/Laguna	CNG	Bus	Utility Van	Rickshaw/ Van	Total	%
Left	18	5	41	15	0	0	0	79	3.72
Through	32	11	1074	374	428	2	0	1989	93.73
Right	2	1	25	14	10	2	0	54	2.54
Total =	55	19	1170	423	451	4	0	2122	
%	2.59	0.90	55.14	19.93	21.25	0.19	0		
PCE	41.25	9.5	1170	317.25	1353	4	0	2895	
Total PCE			2895 passenger car per hour						

Table 3: PCE value of vehicles (Partha 2009)

Vehicle Categories	MoC[6] (2001)
Passenger car	1.0
Truck	3.0
Light good vehicle (Utility van)	1.0
Bus	3.0
Auto-rickshaw (CNG)	0.75
Motorcycle	0.75
Pedal cycle (Bike/rickshaw/van)	0.50

In the field it is observed that two phase fixed controller signal system prevailed but it was implemented manually by traffic police. As a result, variation in cycle time often occurred. For the calibration purpose the signal data taken as average of three cycle time observed in the field within the studied hour.

Total cycle time is found 241 sec, among which 190 sec of green time allocated for major road. As per the calculation, the cycle time distribution for the considered phase systems is displayed in Table 4. The generated model is illustrated in Figure 5.

Table 4: Cycle time distribution for existing, modified two phase and four phase system

Phase	Cycle time (sec)	Effective green time (E-W) in sec		Effective green time (N-S) in sec		Total Lost Time, L in sec
Existing two phase	241	190		45		6
Modified two phase	200	162		34		4
Four phase	200	18(E)	18(W)	82(N)	72(S)	10

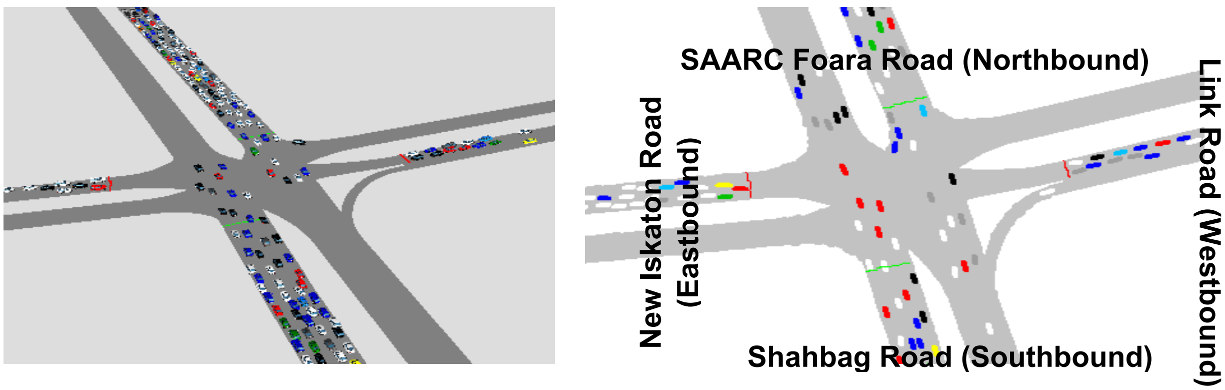

Figure 5: VISSIM 3-D and 2-D Model respectively used in the study

5 Model Calibration and Validation

To achieve high credibility for a simulation model, calibration and validation are of utmost importance (Park 2005). The studied model conform the calibration targets as shown in Table 1, where the limits are within the specified range. The heterogeneity of flow is eliminated by converting all traffic to PCE. The pedestrians are not simulated in the study. Non-lane based flow stands in sharp contrast to micro simulation and rigid in associating vehicles with specific lanes. So, driving behaviour parameters are modified since traffic flow does not follow lanes unlike North American condition. The main parameters for incorporating non-lane based flow are desired position at free flow, lateral distance, diamond shape queuing, consider next turning direction and overtake on same lane. The other parameter's sensitivity analysis is performed. Finally using trial and error method, the calibrated parameters set is found that mimics the field result in terms of flow and travel time. The parameter combination is displayed in Table 5. Comparison of real data observed in the field and simulated data from VISSIM is illustrated in Table 6(a) and (b). The calibrated model is validated for data collected from another working day.

6 Results and Discussion

After studying it is seen that at field condition there is considerable amount of average delay and queue length generation. The average travel time of the vehicles in between the various links is moderately high as well. Especially the right turn from Sahbag to New Iskaton road, face considerable amount of congestion due to the conflict situation with the through movement of traffic coming from SAARC Foara road. Link road and New Iskaton road traffic constitutes minor traffic flow so the signal timing modification for major and minor road may be one solution to improve the present situation.

To achieve better performance in this intersection, various road traffic parameters, characteristics and measures need to be experimented. In this study signal time modification has been implemented and results are compared. Finally the best alternative in terms of efficiency and of the intersection is suggested.

Table 5: Calibrated and modified parameters combination

Parameter	Default Value	Modified Value
Significant Driving Behaviour Parameters:		
Look ahead distance	Min: 0 m, Max: 250 m	30
Look back distance	Min: 0 m, Max: 150 m	30
Smooth close-up Behaviour	unchecked	checked
Average standstill distance	2 m	2.45 m
Additive part of safety distance	2 m	1.90 m
Multiple part of safety distance	3 m	2.98 m
General behaviour	Free lane selection	as it is
Waiting time before diffusion	60 s	as it is
Minimum headway (front/rear)	1 m	0.5 m
Desired position at free flow	Middle of lane	any
Keep lateral distance to vehicle on next lane	unchecked	checked
Diamond shaped queuing	unchecked	checked
Consider next turning direction	unchecked	checked
Collision time gain	2.6 s	3.0 s
Overtake on same lane	unchecked	checked
Minimum lateral distance	1.0	0.90

Table 6 (a): Observed data in field v/s data from simulation

Direction	Individual link flow		Diff. |M-C|	GEH statistic, $\sqrt{\frac{2*(M-C)^2}{(M+C)}}$	Remarks
	Field, C	Model, M			
From SAARC Foara	3336	3254	82	1.43	Difference within 400 veh/hr, for Flow > 2700 veh/hr and within 100 veh/hr, for Flow < 700 veh/hr for more than 85% of the cases. GEH Statistic < 5 for Individual Link Flows for more than 85% of the cases
To SAARC Foara	3152	3062	90	1.61	
From Shahbag	2895	2905	10	0.19	
To Shahbag	3668	3526	142	2.35	
From New Iskaton	504	526	22	0.97	
To New Iskaton	261	224	37	2.33	
From Link road	543	535	8	0.34	
To Link road	194	185	9	0.59	
Sum	14553	14217	336 (2.31%)	2.80	Sum of All Link Flows within 5% of sum of all link counts and GEH < 4 for sum of all link counts.

Table 6 (b): Observed data in field v/s data from simulation

Direction	Travel Times		Difference	Percentage	Remarks
	field	model			
From SAARC Foara	0.69	0.8	0.11	15.94	Road section considered: 10 meter
To SAARC Foara	0.79	0.9	0.11	13.92	
From Shahbag	0.89	0.8	0.09	10.11	
To Shahbagh	0.80	0.9	0.10	12.50	Journey Times, Network: within 15% (or 1 min, if higher)
From New Iskaton	0.76	0.8	0.04	5.26	

To New Iskaton	0.94	0.9	0.04	4.26	for more than 85% cases
From Link Road	1.67	1.9	0.23	13.77	
To Link Road	0.94	0.8	0.14	14.89	

With the existing two phase signal system, if average travel time is considered, it is observed from simulation that modified two phase signal system serves the intersection well for almost all the cases. Typical values are shown in Table 7. For instance, from Shahbag to New Iskaton, the travel time decreases 369 to 318 sec. On the other hand, the four phase signal system generates more time than the prevailing condition at present at a number of cases, making it an ineffective alternative. It is to be mentioned that VISSIM evaluation result of travel time is the average travel time (including waiting or dwell times) determined as the time required by vehicles between crossing the first and crossing the second cross sections (VISSIM manual 5.40, PTV, 2012)

Table 7: Typical comparison of travel time for the generated model

Origin-Destination	Distance in meter	Travel Time in sec		
		Existing two phase signal	Modified two phase signal	Four phase signal
SAARC Foara to Shahbag	886.4	92.10	84.70	227.90
Shahbag to New Iskaton	1371	369.00	318.60	295.00
New Iskaton to SAARC Foara	1363	235.00	220.50	231.40
Link road to Shahbag	622.1	146.30	134.50	322.40

***** Travel time refers to the average travel time (including waiting or dwell times)

From simulation, average total delay per vehicle, average standstill time per vehicle and average number of stops per vehicle is calculated. The total delay is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time. The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other stops in the network. Comparison of delay statistics for the alternative solutions studied are typically illustrated in Table 8. The modified two phase system appears to be a feasible improvement in terms of delay minimization.

Table 8: Typical Comparison of delay for the generated model

Direction	Existing two phase signal			Modified two phase signal			Four phase signal		
	Delay in sec	Stopd in sec	Stops	Delay	Stopd	Stops	Delay	Stopd	Stops
SAARC Foara to New Iskaton	9.20	5.50	0.36	6.50	3.50	0.22	153.60	134.90	1.96
From Shahbag to New Iskaton	252.10	192.20	9.44	201.20	152.70	8.28	177.50	161.90	1.79
Link road to New Iskaton	102.30	92.20	1.63	104.20	94.30	1.53	367.50	341.70	3.58
New Iskaton to SAARC Foara	118.90	102.70	1.97	104.40	89.00	2.03	115.00	105.20	1.27

*Delay is the average total delay per vehicle, Stopd is the average standstill time per vehicle and Stops is the average number of stops per vehicle

In VISSIM, queues are counted from the location of the queue counter on the link or connector upstream to the final vehicle that is in queue condition. For Link from SAARC Foara, queue length improves a lot as shown in Table 9 for modified two phase system. Although maximum queue length at link from Shahbag increases from to 337 to 391 m. The minor roads do not show significant improvement in terms of queue length generation. Four phase system yet again fails to satisfy improvement, as it creates longer queue for almost all approaches.

Table 9: Typical Comparison of queue length for the generated model

Direction	Existing two phase signal		Modified two phase signal		Four phase signal	
	Queue length	Max queue length	Queue length	Max queue length	Queue length	Max queue length
From SAARC Foara	37	264	17	115	345	505
From Shahbag	85	337	85	391	331	505
From New Iskaton	25	72	23	67	25	66
From Link road	43	115	38	116	182	472

* Queue length is the average queue length and queue length is output in units of length not in number of cars

Finally the network performance of the model is checked. The average delay time per vehicle, average speed, total delay and travel time are simulated as displayed in Table 10.

Table 10: Typical Comparison of network performance for the generated model

Term	Existing two phase signal	Modified two phase signal	Four phase signal
Average delay time per vehicle in sec	34.75	29.49	240.36
Average speed in km/hr	28.81	30.25	14.56
Total delay time in hr	69.69	59.14	479.66
Total travel time in hr	224.55	213.95	737.30

The comparison of various data extracted by simulation among the three alternatives (existing two phase, modified two phase and four phase signal system) discussed, it is obvious that four phase system will not be suitable at all and it will worsen the present condition. Most of the parameters suggest that modified two phase system will be more effective in elevating the performance of the studied intersection.

7 Conclusions

Signalized intersections are key elements in the urban transportation network. Increasing traffic demand can exceed the carrying capacity of the intersection during peak periods. Consequently, traffic condition deteriorates. The studied intersection has started facing congestion problem and measures should be taken to improve the prevailing condition. The complex traffic situation prevailed in this study is non-lane based and heterogeneous. The real field condition is simulated by modifying the default driving behavior characteristics of VISSIM. This modification is significant to represent the driving behavior that does not respect lane discipline. Also all the vehicles are converted to equivalent passenger car to induce homogeneity. As per study, it is evident that the modification of existing two phase signal system can be a great alternative to facilitate better performance to the intersection. Four phase signal system implementation will not be suitable as far as the study results suggest. Existing two phase signal's cycle time modification eliminates congestion problem to a great extent and flourish other parameters such as lesser travel time and queue length etc. The model can be tested for other traffic parameter changes other than signal time modification. However, it is obvious that signal time modification can be a feasible alternative to improve performance of the studied intersection. This technique to improve intersection proficiency can be implemented to any North American intersection. Although the driving behavior parameters need to be adjusted due to the fact that there generally exists lane based homogenous or heterogeneous flow. Congestion in intersections is a waste of money and resources. The studied strategy can be applied to fabricate efficacious intersection that would lead to an efficient urban traffic system.

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