Capacity Analysis of Signalised Intersection using Micro-simulation

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Abstract: Micro-simulation models are rapidly gaining acceptance as promising tools to analyse and evaluate ITS and other traffic control and management measures. Capacity is a primary concept in most of traffic engineering studies, however micro-simulation models generally ignore this concept. There are significant numbers of studies on capacity analysis based on analytical approaches including Highway Capacity Manual (HCM) and the Australian Research Report (ARR 123). The analyses conducted using micro-simulation reflected under representation of capacity however such studies are limited in numbers and scope. This paper reports an investigation conducted using AIMSUN micro-simulation model to analyse the capacity and queue discharge flow rate at a signalised intersection in Auckland. The micro-simulation model was calibrated using realistic local parameters to represent the real world situation. The results from this calibrated model were first verified against the data collected from loop detectors and then compared with results from analytical approaches including HCM and ARR 123. The comparative analysis showed that micro-simulation presents reasonable representation of actual traffic conditions when flow volumes are high. In the light of favourable research findings, it is concluded that AIMSUN is a viable tool for the evaluation and capacity analysis of a signalised intersection.

1. INTRODUCTION

Microscopic simulation models are rapidly gaining acceptance as promising tools to analyse and evaluate ITS and other traffic control and management measures by traffic engineers and transportation professionals. Microscopic models describe the system entities and their interactions at high level of details. Its applications in solving complex traffic engineering problems have received popularity as well as criticism. The capability of its usefulness in predicting various factors such as desired speed and gap acceptance, in addition to analyse roadway traffic conditions showed a great potential to explore. These models track and record the individual movements of vehicles which help and allow the analyst to test a wide range of roadway configurations and operational conditions that far exceed the limits of typical analytical tools. Additionally, present micro-simulation models include highly sophisticated graphical user interfaces (GUI) that allow visual displays and demonstration of traffic operations on a computer screen which was previously not possible in conventional computational tools. This characteristic enhances its understanding within the transportation professionals as well as others outside this profession to visualize the traffic operations and it can be presented in public meetings. However, micro-simulation models are criticised for their few limitations when compared to analytical tools due to its time consumption and extensive resource utilization.

Prior to development of micro-simulation models, analytical methods were typically employed in studies to plan and improve roadway facilities. These methods can estimate capacity, delay, level of service and other parameters for a given set of roadway conditions. Capacity is a primary concept in most of the traffic engineering studies, whereas micro-simulation models generally ignore this concept as micro-simulation models are built on car following and lane changing theories (as cited in Akçelik and Besley, 2001). Analytical approaches including Highway Capacity Manual (HCM) and the Australian Research Report (ARR 123) attracted many researchers to conduct studies on capacity analysis (McGhee and Arnold, 1997; Akçelik, 2003; Buckholz, 2009); in contrast, only few researchers used micro-simulation approach to study capacity analysis. The emphasis on these studies was mainly on validation process of micro-simulation model (Bayarri, et al., 2004; Wan, et al., 2005; Gagnon, et al., 2008). These studies on micro-simulation, though limited in scope and less in number, have reported under representation of actual capacity by the model. In a recent work conducted by Andjic and Matthew (2008), hypothetical data was utilized to investigate capacity and queue discharge flow rates and the results are yet to be validated using field data observations. While establishing correlation between modelled and theoretical values, these researchers presented interpretation of micro-simulation outputs in traffic engineering terms. Sometimes these interpretations are compromised with some unrealistic data inputs (like reaction times) to make the outputs closer to real values (Andjic and Matthew, 2008; Rajasakran, 2008).

This paper endeavours to test and apply compatibility techniques as presented by Akcelik and Besley (2001) to investigate capacity and queue discharge flow rates at a signalised intersection using AIMSUN micro-simulation software (version 6.0.1). The study is carried out to assess the compatibility of car following model running in AIMSUN micro-simulation model, to analytical approaches by employing the data directly taken from loop detectors. The scope of this study is limited to isolated signalised intersection operations to make it comparable with analytical approaches. The primary objective of this research is to review and study the micro-simulation approach for the possible implementation as an alternative to analytical method. More specifically, the objectives of this study are listed as follows:

1. To evaluate the implementation of micro-simulation on a signalised intersection and compare its results with traditional analytical approaches.
2. To examine the ability of AIMSUN micro-simulation model to produce capacity and delay estimates at signalised intersections that are reliable and valid with standard traffic flow theory.
3. To study and evaluate the micro-simulation as an alternative approach for capacity analysis for signalised intersections.

The remaining part of this paper is organised in five sections. In the next section, detailed methodology is presented on framework of this study along with the test bed description, measures of effectiveness adopted in the analysis, calibration and validation process of micro-simulation model. The data used for this study is presented in the traffic count data section. Data analysis is split into calibration process and validation process. Finally capacity analysis is carried out in section 5 and findings of this study are discussed in discussions in section 6.

2. METHODOLOGY

Two analytical capacity estimation methods and a micro-simulation model were investigated by identifying their assumptions, limitations and strengths. The micro-simulation model used for this study was AIMSUN which was developed by a research group at the Laboratorio de Investigación Operativa y Simulación in the Department of Statistics and Operations Research of the Universit at Politècnica de Catalunya (Barcelo and Casas, 2002). Results of the micro-simulation model were compared with the results of analytical models in order to demonstrate the consistency of the micro-simulation model with analytical solutions. The test bed used for this study is an urban signalised intersection. A description of the micro-simulation and analytical approaches used in the study is presented in a flow chart in Figure 1 and described in subsequent sections. This flow chart presents the methodology used for this research.

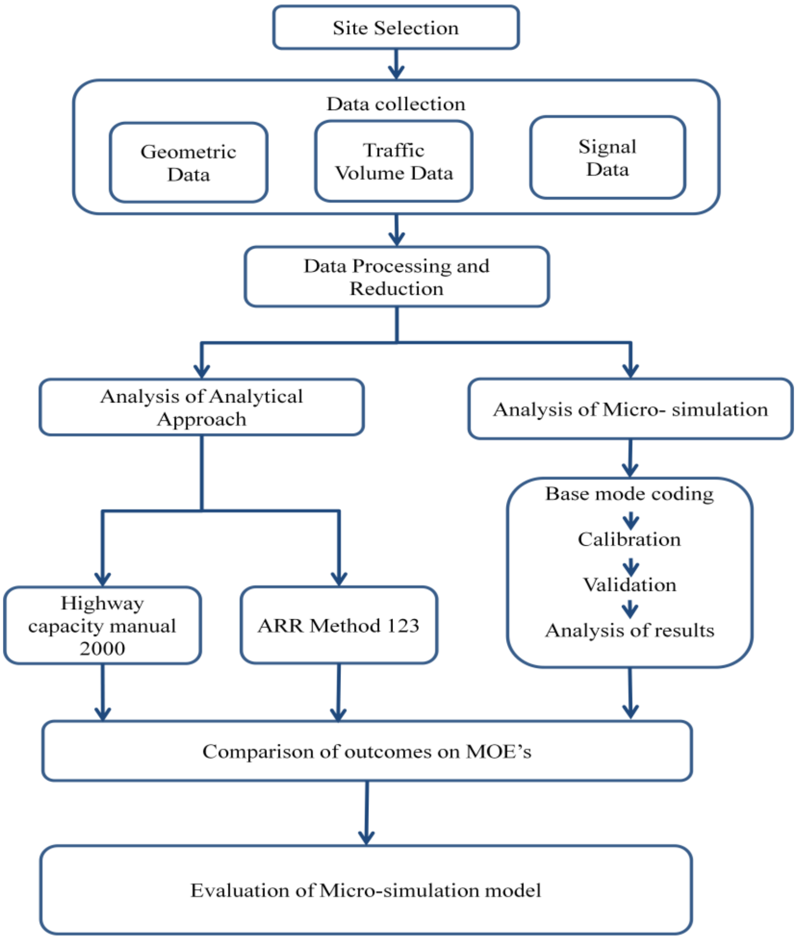

Figure 1: Flow Chart for study

2.1 Test Bed and Test Scenario

An urban intersection has been selected for comparative performance study. The layout and phasing information of this intersection is shown in Figure 2. For this study, the required data was split into three sections; traffic volume data, signal data, and geometric data. Traffic volume data and signal data was requested from the SCATS help desk for the mid November, 2008. The data from SCATS loop detectors was provided in the form of 15 minute traffic counts along with phasing information. The obtained data was used for micro-simulation model as a baseline data and subsequently it was further used in calibration process. The same data was used as an input for analytical models.

For easy retrieval and analysis, data was imported into spreadsheets. As a first step, the obtained data was filtered and segregated into morning peak times and evening peak times in order to obtain the peak flow hours. Two peak hours were selected each one from morning peak traffic flow and evening peak traffic flow. A neutral day Tuesday was selected for comparative analysis. Based on initial data filtration, two peak traffic flow periods were identified as 8AM to 9AM in the morning and 5PM to 6PM in the evening.

Percentage turning movement is an important input parameter in the preparation of micro-simulation model. Although turning percentages were not included in the data provided by the SCATS, a data reduction technique was utilized to calculate turning percentages. These percentages were calculated on the basis of traffic counts on each lane; as location of loop detectors near stop line gives a good indication of vehicle's turning decision. Signal data provided by the SCATS system was in average value of 15 minutes time span for morning and evening peak hours with maximum allocated cycle time of 120 seconds. Phase timings were calculated based on this average data and an inter-green time was obtained.

Figure 2: Layout and Phasing information (SCATS Data)

2.2 Measures of Effectiveness

Presently, capacity estimation procedures of analytical approaches including HCM, and ARR 123 are the principal means to investigate traffic performance and capacity analysis at signalised intersections. Traditionally, traffic management systems are being planned, designed and implemented through these procedures. Keeping this in view, these analytical techniques are taken as a reference line to assess the capabilities of alternative approach. As a result measures of effectiveness calculated by these analytical methods were compared to the corresponding behaviour of micro-simulation.

To compare the measures of effectiveness, the most used performance measures were selected from the analytical models; capacity and v/c ratio (degree of saturation). The models were also compared with delays calculated in analytical methods and micro-simulation. The purpose of choosing these measures of effectiveness was the difference in the treatment methodology in analytical models and micro-simulation models for traffic analysis.

2.3 Model Calibration and Tuning

After base model coding, the most important step was to calibrate the model to ensure that the accuracy of the model outputs. AIMSUN is considered as software which does not need much calibration (Fang and Elefteriadou, 2005). The car following model in AIMSUN has been tested and calibrated in various research studies including research group from Robert Bosch Gmb H, (Manstetten, et al., 1998). The Bosch car-following test was conducted on different micro-simulation models commonly used in Europe and North America. The results in the test show that the AIMSUN car-following model was able to present fairly good replication of observed values.

Economic Evaluation Manual (EEM-I) presents GEH statistics concept for transportation model validation. GEH statistics is a chi-squared statistics that is designed to be tolerant of larger errors in low flows. It can be calculated as:

$$GEH = \sqrt{\frac{2(q_{model} - q_{obs})^2}{(q_{model} - q_{obs})}} \tag{1}$$

Where q_{obs} is observed hourly flow and q_{model} is modelled hourly flow.

Economic evaluation manual recommended ranges of GEH statistics for model checks (Economic Evaluation Manual, 2008):

- At least 60% of individual link flows should have GEH less than 5.0
- At least 95% of individual link flows should have GEH less than 10.0
- All individual link flows should have GEH less than 12.0
- Screenline flows should have GEH less than 4.0 in most cases

Another recommended criteria mentioned in EEM-I is percentage root-mean-square-error (RMSE) which is calculated as;

$$RMSE = \frac{\sqrt{\frac{\sum(q_{model} - q_{obs})^2}{Number\ of\ counts - 1}}}{\left[\frac{\sum q_{obs}}{Number\ of\ counts}\right]} \tag{2}$$

According to EEM-I criteria, RMSE should be less than 30%.

The process of calibration was carried out by setting input values according to recommended saturation flow values based on local conditions. The table below shows the calibrated measures adopted in the model. The realistic values are selected for this study based on the recommendations in literature (Ranjitkar, et al., 2005; Xin, et al., 2008).

Table 1: Input parameters after calibration

Simulation Date	November 11, 2008
Detection Cycle	0.75 seconds
Car following model	Deceleration estimation (avg. Of follower & leader)
Queuing up speed	1 m/sec
Queuing leaving speed	4 m /sec
Speed	50 km/h
Reaction time	0.75 seconds
Reaction time at stop	1.35 seconds
Arrival distribution	Normal distribution
Acceleration rate	
max	2 m/sec^2
min	1.2 m/sec^2
Normal deceleration rate	
max	4.5 m/sec^2
min	3.5 m/sec^2

3. TRAFFIC COUNT DATA

The New Zealand Transport Agency (NZTA) provided data for this study. Traffic count data from SCATS system loop detectors representing the flow of vehicles in 15 minutes interval was provided for this study. Figure 3 shows the 24 hours traffic flow pattern on all approaches for Tuesday, 11 November 2008 traffic. From the Figure 3, it is evident that traffic volume start to increase at 7 AM in the morning to 9AM and after 9AM traffic data remains flat at an average flow rate till the evening peak hours starts. Evening peak time starts at 4PM till 6PM. It is observed from the Figure 3, that approach 7 & 8 provides high traffic volumes in the morning peak hours while approach 1 and 2 shows high flow rate during evening peak hours.

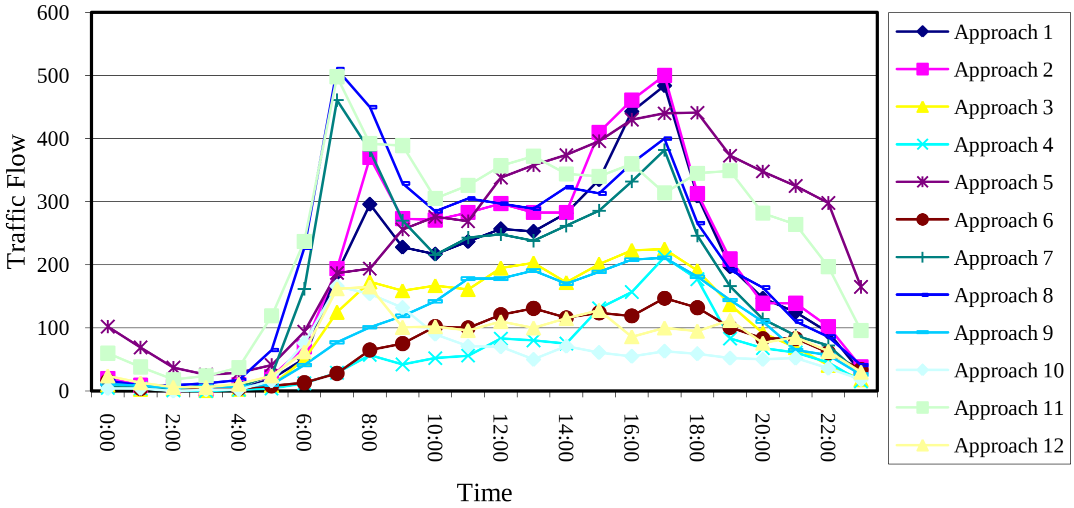

Figure 3: Traffic flow for 24 hours on Tuesday

The input data required for signalised intersection to define the traffic control parameters were location of signals, the signal groups into which turning movements are grouped, the sequence of phases for each one of the signal groups that have right of way, the offset for the junction and the duration of each phase.

Most of the major urban intersections in Auckland region use Sydney Co-ordinated Adaptive Traffic System (SCATS) loop detectors to record traffic volumes. SCATS is a traffic management system that operates in real time, adjusting signal timings in response to variations in traffic demand and system capacity as they occur. SCATS manages groups of intersections through its unique control philosophy rather than treating intersections as an isolated entity. At the subject intersection twelve loop detectors were in place at through and right turn approaches to detect vehicular flow. The data provided by the SCATS help desk included phasing information for the same period which is shown in Figure 2. It is evident from the Figure that 12 phases are available to meet with varying traffic demands in this intersection. However, at peak traffic times, the sequence of phasing is reduced to four phases “A”, “D”, “E” and “G” to handle traffic at this intersection. For calculation of lane group capacity, it was required to have the exact green time allocation data in a signal cycle. On further request, signal phasing information for 15 minute time was provided in the form of maximum and minimum values of phasing split information. From the signal phasing data, maximum and minimum values are derived for each phase split which is shown in Table 2.

Table 2: Signal Timings at peak hours

Phase	Phasing Time (Sec)		
	Minimum	Maximum	Extension
A	26	41	1
B	-	-	-
C	-	-	-
D	17	27	1
E	22	46	1
F	-	-	-
G	12	25	1

4. DATA ANALYSIS

4.1 Calibration Process

In order to use these scenarios in a way that it produces the best possible simulation results, it is important to validate these scenarios. The first step in any micro-simulation analysis is to calibrate the input parameters according to local conditions. Vehicle type used in the study included the category “Car”. The parameters used for this vehicle category were presented in Table 1.

The sensitivity of the micro-simulation model was checked against reaction time and it was found that at 0.75 seconds, micro-simulation produces results comparable to field observations. Figure 4 shows the results of sensitivity analysis of micro-simulation model.

Micro simulation model was calibrated by adjusting saturation flow rate. Saturation flow rate is an important characteristic in capacity calculations and it is adjusted for prevailing traffic conditions such as lane width, percentage of heavy vehicles, grades, right turns, left turns, parking arrangements, public transport blockage, and right turn blockage. ARR123 defines saturation flow as the maximum steady flow rate from the queue during the green period of the signal phase. Akcelik also mentioned the lost time concept in saturation flow which is an integral part of the saturation flow concept (Akçelik, 1995).

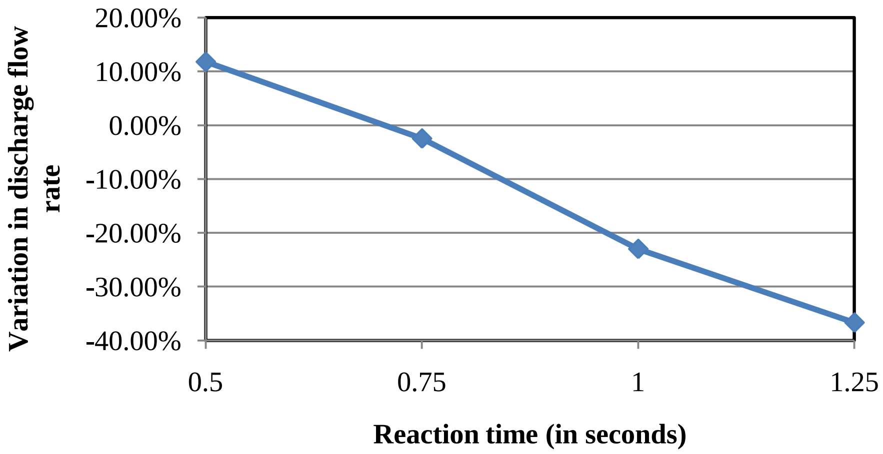

Figure 4: Model sensitivity against reaction time

The saturation flow rate was derived in micro-simulation model by maintaining a continuous queue situation and by allowing a warm up simulation time of 20 minutes. The rounded up average of maximum flow rate in three simulations was used as a saturation flow rate in the analysis. Base saturation flow rates for analytical models and micro-simulation model are presented in Table 3.

Table 3: Base Saturation flow rates

Approaches	Analytical Method		Micro-simulation
	HCM	ARR 123	
Flow Rate	1900	1850	1800

4.2 Validation Process

As a first step the results of micro-simulation model is validated in order to check the consistency of the model. A comparison of one hour micro-simulation results with SCATS data is presented in Table 4. From lane wise comparison, it was observed that the variations are high at lane 4, 6 & 12 in the morning peak hour. Lane 4 and 6 showed a highest variation of 35.09% and 23.08% in south bound approach respectively and 13.94% variation were observed in lane 12. In evening peak hours, high percentage variations were noted at lane 3 and lane 10 with variation of 9.78% and 17.46%. Lane 4 showed a variation of 7.08% in south bound approach. It is to be noted that the percent error is high at approaches with low volume due to its high sensitivity in change of even small numbers. In comparing AM peak and PM peak, it is observed that the PM peak has a uniform variation on all approaches. AM peak shows variation from 0.99% (negative) at lane 9 to 35.09% (negative) at lane 4. Standard deviation for percent error is noted as 14.72% for morning peak hour and 7.59% for evening peak hour.

Economic Evaluation Manual (2008) recommends GEH statistics for transportation model validation. GEH statistics for study model are presented in the last columns of Table 4. The minimum GEH was noted at lane 2 as 0.18 and maximum GEH was noted as 1.53 at lane 8 during PM peak. PM peak results reflect all values of GEH under 2.00. In the morning peak hours, the result varying from 2.44 at lane 4 to 0.10 at lane 9. These results confirm the recommended criteria of EEM for transportation model check. RMSE for morning peak and evening peak were noted as 10.86% and 5.83 % which is well below the threshold criteria of 30%.

Lack of lane utilization factor in AIMSUN model is one of the reasons for the variations and Table 5 strengthen this hypothesis. Table 5 presented the movement wise comparison of the queue discharge flow rate. East bound traffic is critical in morning peak hours while west bound traffic is critical in evening peak hours. Deviation of east bound through traffic in morning peak hour is calculated as 6%, however in evening peak hour the deviation of 1% showed a realistic replication of original traffic flow in west bound through traffic. Evening peak provided fairly reasonable results for all approaches which showed that evening time have constant traffic pressure for whole hour and therefore further analysis is conducted on evening peak hour.

Earlier, Table 2 showed the maximum and minimum values of phasing time at evening peak hours. To allocate effective green times, lost time was calculated based on Table 2. It is seen that the most appropriate value for lost time is 16 seconds, with 4 seconds inter-green time between subsequent phases. The procedure for estimating the signal timing was adjusted according to appendix B, Chapter 16 – signalised intersections of HCM 2000. HCM 2000 suggested the default target v/c value of 0.90. With the equations, B16-2 and B16-4 of HCM 2000, phase arrangement has been adjusted which is presented in Table 6.

Table 4: Lane wise comparison of queue discharge (One hour simulation results)

Lane	Micro-simulation		SCATS Data		Percent Error		GEH	
	AM Peak	PM Peak	AM Peak	PM Peak	AM Peak	PM Peak	AM Peak	PM Peak
1	269	467	296	484	9.12%	3.51%	1.61	0.78
2	327	504	370	500	11.62%	-0.80%	2.30	0.18
3	161	203	173	225	6.94%	9.78%	0.93	1.50
4	77	227	57	212	-35.09%	-7.08%	2.44	1.01
5	180	410	194	440	7.22%	6.82%	1.02	1.46
6	50	151	65	147	23.08%	-2.72%	1.98	0.33
7	413	405	381	382	-8.40%	-6.02%	1.61	1.16
8	471	370	450	400	-4.67%	7.50%	0.98	1.53
9	102	203	101	211	-0.99%	3.79%	0.10	0.56
10	160	74	154	63	-3.90%	-17.46%	0.48	1.33
11	362	311	392	314	7.65%	0.96%	1.55	0.17
12	142	97	165	100	13.94%	3.00%	1.86	0.30

RMSE (%) for Morning Peak = 10.86 %
RMSE (%) for Evening Peak = 5.83 %

Table 5: Movement wise comparison of simulation and loop detector data

Approach		EB		WB		NB		SB	
Flow Direction		TH	RT	TH	RT	TH	RT	TH	RT
Morning peak	Microsimulation	884	102	596	161	522	142	257	50
	Loop detector	831	101	666	173	546	165	251	65
	Variation	6%	1%	-11%	-7%	-4%	-14%	2%	-23%
Evening Peak	Microsimulation	775	203	971	203	385	97	637	151
	Loop detector	782	211	984	225	377	100	652	147
	Variation	-1%	-4%	-1%	-10%	2%	-3%	-2%	3%

Table 6: Phase arrangement (evening peak hours)

Phase Arrangement							
Phase number	A	B	C	D	E	F	G
Lane group							
Effective green time, g(s), g= G+Y-tL	37			15	35		17
Green ratio, g/c	0.308			0.125	0.292		0.142

5. CAPACITY ANALYSIS

Capacity analysis of the intersection was carried out under a set of conditions detailed as under;

- Analysis is conducted in the PM peak time.
- Comparison of micro-simulation model is conducted with methodology described in ARR 123 and HCM methods.
- The phase timings for this study is assumed as fixed to make comparison with ARR 123 and HCM.

5.1 Using HCM

Table 7 presented the HCM 2000 calculations for capacity analysis. From this table, it can be seen that the symmetry of intersection divided all the movements in two groups. This symmetry of intersection is reflected in saturation flow rate which is presenting the two values for through and right turning movements based on prevailing traffic conditions. Lane group capacity of east bound and west bound traffic is same due to equal allocated green time in phase A. Lane group capacity for EB and WB through traffic is 1116 vehicles against maximum traffic flow of 980 vehicles at WB through approach. Volume to capacity ratio for WB through approach is 0.88 which denotes that this approach is reaching at near capacity. North bound approach gives the lowest v/c ratio of 0.36 for through traffic which is an indication of low traffic volume towards CBD area in evening peak hour.

HCM reports capacity in terms of Level of Service (LOS). LOS value was calculated based on the delay values at corresponding approach. LOS is a prompt indicator of functional performance of a section. EB right turning approach was at LOS of “F” while north bound through traffic was at LOS “C”. Both highest traffic carrying approaches, through WB and EB lanes, were at a level of service “D”. WB right turning approach and SB right turning approach was indicating a level of service “E” for the analysis period. Control delay value of 92.51 seconds showed the highest delay occurrence at right turning EB movement. SB right turn movement also indicated delay value at 76.26 seconds which is closer to level of service “F” threshold of 85 seconds. Minimum delay of 34.65 seconds is observed at NB through traffic.

5.2 Using ARR 123

ARR 123 does not provide level of service (LOS) equivalent. The capacity is calculated based on the saturation flow rate and allocated green time to the particular approach. Table 8 presented the calculations of lane group capacity and delay estimates based on ARR 123 methodology. Average number of vehicles arrival is noted at 32.8 vehicles per signal cycle in west bound through traffic which is the highest arrival rate in the evening peak hour and justify the maximum green time allocation. North bound right turning approach indicated a lowest arrival rate of 3.33 vehicles per signal cycle. For lane group capacity, the intersection can be split into two groups with through lane saturation flow rate of 3700 and right turning saturation flow rate of 1850. This group indicated that EB and WB through traffic had equal lane group capacity of 1140 vehicles per second. Degree of saturation for WB through approach and WB right turning approach was noted as highest as 0.86. Degree of saturation for NB through traffic was noted as 0.35 which is lowest value for all approaches. According to ARR 123, as highest degree of saturation is within 0.8 and 0.9, the intersection is operating under satisfactory functional conditions.

Table 7: Lane group capacity, control delay and LOS determination (HCM method)

	EB		WB		NB		SB	
	TH	RT	TH	RT	TH	RT	TH	RT
Adjusted flow rate, v (veh/h)	844	212	980	184	384	80	632	164
Saturation flow rate, s (veh/h)	3619	1719	3619	1719	3619	1719	3619	1719
Phase	A	G	A	G	E	D	E	D
Lane group capacity, c=s(g/C), (veh/h)	1116	244	1116	244	1057	215	1057	215
v/c ratio, X	0.76	0.87	0.88	0.75	0.36	0.37	0.60	0.76
Flow ratio, v/s	0.23	0.12	0.27	0.11	0.11	0.05	0.17	0.10
Total Green ratio, g/c	0.31	0.14	0.31	0.14	0.29	0.13	0.29	0.13
Uniform delay, d1=	37.43	50.42	39.36	49.50	33.68	48.18	36.47	50.78
Delay, d = d1(PF) +d2+d3 (s/veh)	42.386	92.514	50.438	71.271	34.652	53.126	39.009	76.259
LOS by lane group (Exhibit 16-2)	D	F	D	E	C	D	D	E
Delay, Approach	52.45		53.73		37.84		46.68	
Intersection delay	49.61							

Table 8: Lane group capacity and delay (ARRB 123)

	EB		WB		NB		SB	
	TH	RT	TH	RT	TH	RT	TH	RT
flow rate, q (veh/h)	782	211	984	225	377	100	652	147
Avg. number of arrivals qc (veh/cycle)	26.067	7.0333	32.8	7.5	12.567	3.3333	21.733	4.9
Saturation flow rate, s (veh/h)	3700	1850	3700	1850	3700	1850	3700	1850
Phase	A	G	A	G	E	D	E	D
Lane group capacity, Q=s(g/C), (veh/h)	1140	263	1140	263	1080	231	1080	231
Degree of saturation, x = q/Q	0.69	0.80	0.86	0.86	0.35	0.43	0.60	0.64
Arrival Flow ratio,y = q/s	0.21	0.11	0.27	0.12	0.10	0.05	0.18	0.08
Total Green ratio, u=g/c	0.31	0.14	0.31	0.14	0.29	0.13	0.29	0.13
Delay, D (number of vehicles)	7.75	3.65	11.88	4.60	3.20	1.06	6.33	1.91
Delay, d (sec)	35.67	62.20	43.47	73.54	30.59	38.15	34.95	46.87
Approach Delay, (sec)	41.31		49.07		32.17		37.14	
Intersection Delay, (sec)	41.80							

5.3 Using Micro-simulation Approach

Table 9 presented the capacity calculations in micro-simulation analysis. Converting the micro-simulation flow values in to the capacity values with saturation flow rate of 1800, lane group capacity is shown in the same table. Maximum capacity under the current phase arrangement is attained at 1109 vehicles per hour for WB through traffic approach and EB through traffic approach. Degree of saturation indicator showed that WB through traffic approach has exceeded the values of 0.85. According to HCM intersection status criteria, the WB through approach was noted near capacity condition. WB right turn approach and EB right turn traffic approach is displaying the value of v/c ratio of 0.79. WB through traffic approach and WB right turning traffic approach was noted with v/c ratio of 0.86 and 0.84. Contrary to the analytical approaches, NB through approach shows as lowest v/c ratio of 0.37.

AIMSUN calculates section wise delays. It was observed that vehicles at WB section have highest delay values of 55.69 seconds. These values are obtained during first fifteen minutes of simulation with zero initial queues. Minimum delay is observed at NB approach with 37.9

seconds. Delay values calculated by AIMSUN are comparable to delay values calculated by HCM 2000 and ARR 123.

Table 9: Lane group capacity and delay (MICRO-SIMULATION analysis)

	EB		WB		NB		SB	
	TH	RT	TH	RT	TH	RT	TH	RT
Adjusted flow rate, v (veh/h)	775	203	971	203	385	97	637	147
Saturation flow rate, s (veh/h)	3600	1800	3600	1800	3600	1800	3600	1800
Phase	A	G	A	G	E	D	E	D
Lane group capacity, c=s(g/C), (veh/h)	1109	256	1109	256	1051	225	1051	225
v/c ratio, X	0.70	0.79	0.88	0.79	0.37	0.43	0.61	0.65
Flow ratio, v/s	0.22	0.11	0.27	0.11	0.11	0.05	0.18	0.08
Total Green ratio, g/c	0.31	0.14	0.31	0.14	0.29	0.13	0.29	0.13
Delay	55.39		55.69		37.90		41.56	
Intersection delay	49.85							

5.4 Relationship between Micro-simulation and Analytical Approaches

In determination of volume to capacity ratio, the graph in Figure 5 and 6 presents a useful indication for capacity comparison. Value of R^2 of 0.926 with RMSE value of 9.13% shows that a linear correlation is present between micro-simulation and HCM 2000. A closer relationship can be seen between micro-simulation and ARR 123 approach with R^2 of 0.983 and TMSE of 4.05% in Figure 6. These values indicates that a correlation can be established between micro-simulation and analytical models.

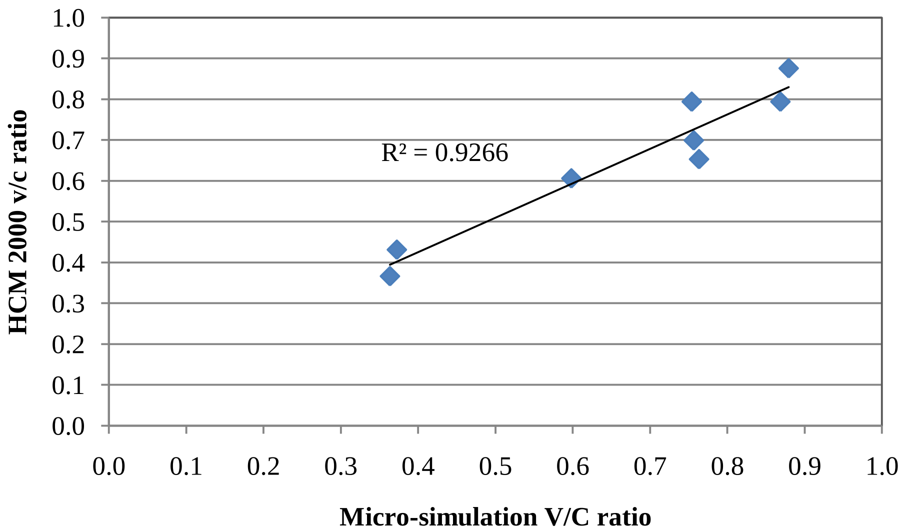

Figure 5: Scatter plot of v/c ratio for HCM 2000 and micro-simulation

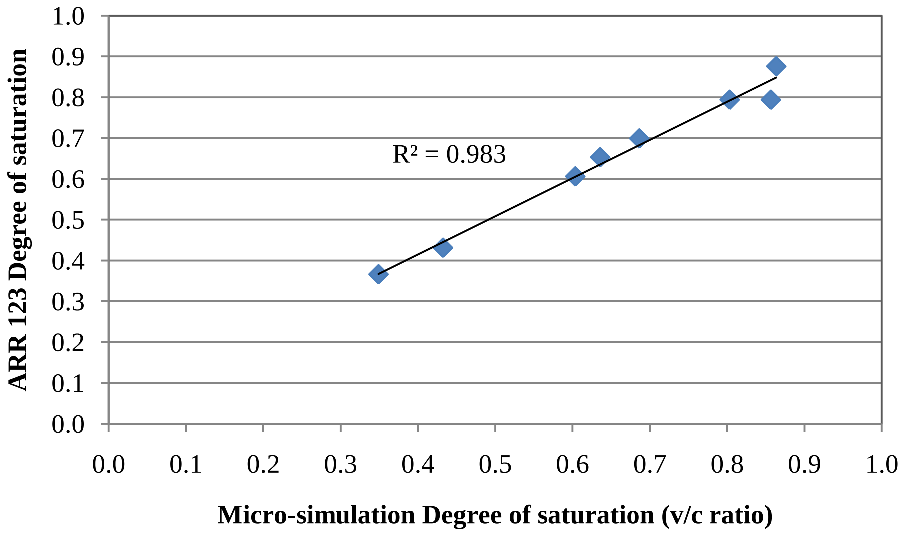

Figure 6: Scatter plot of v/c ratio for ARR 123 and micro-simulation

6. DISCUSSIONS AND CONCLUSIONS

This study presented the comparison of the micro-simulation and analytical models results in view of alternative approach for capacity estimations. v/c ratios and delays are determined in an effort to analyse the compatibility of micro-simulation approach in capacity analysis. An isolated signalised intersection was selected as a test bed and field data was collected to use as an input in micro-simulation and analytical approaches. Different levels of variations were observed from the micro-simulation results. Lane wise comparison between micro-simulation generated results and loop detector data has shown some variations in the morning and evening peak times. It was noted that the micro-simulation generated data fits well when discharge flow rate approaches the capacity and error increases as discharge flow rate decreases. The micro-simulated data fits well with the evening peak hours loop detector data and represent the actual flow conditions with a RMSE error value of 5.83%. However, the variations are observed in morning peak hours with RMSE of 10.86% but still it is in the acceptable limit of 30%. When comparing the results approach wise, it was observed that the flow conditions at or near saturation flow rates were reproduced in close propinquity by AIMSUN and where flow conditions are less than saturation flow, the variations are considerable though within the allowable range of maximum error.

The comparison with analytical approaches shows that a correlation exists between v/c ratios calculated by AIMSUN results with the results of analytical approaches. The close correlation is observed with ARR 123 with R^2 value of 0.983 and RMSE value of 4.05%. This correlation of v/c ratio calculated by AIMSUN results is also noted with HCM 2000. It is observed that AIMSUN provides acceptable saturation flow rate without fake adjustments which in turn provides lane group capacity almost identical to HCM 2000. This shows the model transparency in prediction of traffic flow conditions.

The delay values predicted from the micro-simulation analysis suggested that it is predicting an acceptable level of comparability with analytical approaches. AIMSUN does not report lane wise delays; instead, it reports section wise delays. This gives analytical approaches an edge that report lane wise and movement wise delays. Micro-simulation reported occurrence of high delays of 55.69 seconds at WB approach. Comparing with analytical methodology, this high delay is due to the micro-simulation's different treatment of delay estimation in which it calculates the delay in terms of time spent when a vehicle enters in to the system till it leaves.

The results obtained in this study are comparable with analytical approaches and reflected a possible implementation of AIMSUN micro-simulation model to be used for the evaluation of capacity analysis of signalised intersections. However few limitations of AIMSUN were observed during this study. These limitations are generally associated with editing and coding of the model. Among them the most important one is absence of the lane utilisation factor. This study revealed that micro-simulation approach can address some of the limitations of the analytical approaches in capacity analysis of signalised intersection. The major contributions of this paper can be split into three folds. Firstly, it compared the most common analytical methods used for capacity analysis and identified the limitations and assumptions of these methods. Secondly, it endeavoured to demonstrate the validity of estimating performance measures pertaining to capacity analysis. Thirdly, it investigated the potential of validated micro-simulation model to evaluate conditions that are comparable to analytical methods. The investigations in this study were limited to AIMSUN micro-simulation software and it is recommended that further evaluations are conducted with other micro-simulation models to confirm and lay down guiding rules and principles to use these models effectively in traffic engineering problems.

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