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PERFORMANCE EVALUATION OF ADVANCED TRAFFIC CONTROL SYSTEMS AT SIGNALISED INTERSECTIONS FAR FROM ADJACENT INTERSECTIONS

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ABSTRACT

Advanced Traffic Control Systems (ATCS) have been recognised as one of the most direct methods for relieving urban traffic congestion. However, the applications of the systems in large cities in developing countries are unique because road networks in these cities face more severe transportation problems than those in developed countries. Furthermore, some of signalised intersections lie close, but others far from adjacent intersections. The aim of this paper is to evaluate the performance of ATCS at intersections with far distance to adjacent intersections and to recommend how to improve traffic performance with given constraints of severe transportation problems. Road network in Bandung, Indonesia was used as a case study. Microscopic traffic simulation was conducted to evaluate the performance of ATCS. It is shown that on average, traffic performance measures under Fixed Time traffic control system were similar or better than those under ATCS. In conclusion, the application of ATCS at intersections far from adjacent intersections is not effective.

Keywords: *advanced traffic control systems, far distance to adjacent intersections, severe transportation problems, developing country*

INTRODUCTION

Traffic congestion is increasingly becoming a severe problem in many large cities around the world. The problem is more complex in developing countries where cities are growing much faster than those in the developed countries. The average annual population growth in developing countries is estimated at around five percent compared to 0.7 percent in developed countries [1].

Advanced Traffic Control Systems (ATCS) are one of the ITS (Intelligent Transportation Systems) technologies that have been used as a tool to ease congestion problems [2, 3] in many large cities in developing countries. However, the application of ATCS in developing countries is unique because cities in developing countries face more severe transportation problems than those in developed countries [1]. Road networks in these cities usually have a grid pattern only in the centre of the city. Some of signalised intersections lie close to adjacent intersections, but other lie far from adjacent intersections.

The application of ATCS at signalised intersections with close distance to adjacent intersections is noteworthy in order to accommodate changing conditions, reduce delay and stops, maximise traffic flow in respond to traffic demand and improve safety. On the other hand, the application of ATCS at signalised intersections far from adjacent intersections (300m – 400m or > 400m) may not be effective because the long stream between two intersections can accommodate a larger number of traffic movements, a larger number of vehicles in the same road capacity, higher speed, and longer queue length without direct impact on traffic congestion at the intersections.

The aim of this paper is to evaluate the performance of the systems at intersections with far distance to adjacent intersections, and recommend improvements of traffic performance with given constraints of severe transportation problems. Road network in Bandung, Indonesia, where SCATS (Sydney Coordinated Adaptive Traffic Control Systems) was implemented in June 1997 as a pilot project, were used as a case study. Microscopic traffic simulation AIMSUN (Advanced Interactive Microscopic Simulation for Urban and Un-urban Network) were conducted to evaluate the performance of ATCS at the intersections during morning peak (7:00 – 8:00am), off peak (10:00-11:00am), and afternoon peak (4:30-5:30pm) periods. The findings of this study are believed to be applicable not only to Bandung, but also beneficial for other large cities in Indonesia and other developing countries that have similar specific local conditions.

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ATCS IN ROAD NETWORK IN DEVELOPING COUNTRIES

ATCS have been recognised as one of the most direct methods for relieving urban traffic congestion. ATCS are effective tools in coordinating traffic signals to reduce delay, stops and fuel consumption [4]; maximise traffic flow, respond to traffic demand [5] and improve safety [6].

Advanced Traffic Control Systems SCATS

A number of traffic control systems are currently used around the world, for instance SCATS (Sydney Co-ordinated Adaptive Traffic System), SCOOT (Split Cycle Offset Optimisation Technique), BLISS (Brisbane Linked Intersection Signal System) and STREAMS (Synergised Transport Resources Ensuring an Advance Management System).

SCATS has gained popularity in Australia, Asia, and more recently in North America [6]. SCATS is applied in many large cities in developing countries in Asia including Singapore, Cebu and Manila in the Philippine, Sandakan and Serembam in Malaysia, Sha Tin, Hong Kong and Guangzhou in China, Bandung and Jakarta in Indonesia, Brunei Darussalam, and Suva in Fiji [7, 8]. In addition SCATS was installed in 36 cities worldwide and controls around 7,000 traffic lights [3, 9].

SCATS was developed by the New South Wales Department of Main Roads Australia. SCATS is a dynamic control system that can accommodate changing conditions using real time input from a number of different sources such as road detectors at the stop line, video cameras (CCTV), and pedestrian push buttons. This system updates intersection cycle length, stage split, and co-ordination with adjacent intersections within a road network to meet the variation in demand and improve traffic flow [2]. SCATS is currently running in Bandung and is the subject of evaluation in this study.

Specific Local Conditions of the Road Network

SCATS applications in developing countries are noteworthy, because cities in these countries face more severe transportation problems than those in developed countries [1]. These cities has low road network densities, only six up to 11 percent of the total city area compare to 20 up to 25 percent in large cities in developed countries, such as London, Paris and New York [10]. This limited road infrastructure has to serve city residents with high population density and has also to serve vehicles with high annual vehicle growth rate [11].

In order to achieve a good traffic performance, SCATS application in developing country should be based on the specific local conditions that commonly occur in these large cities. Some of these specific conditions include irregular pattern of road network, grid pattern only in the centre of the city, various numbers of distances between intersections, high level of side friction in connection with on street parking and street vendor activities, poor lane discipline, and poor lane use regulations.

With specific geometric and traffic conditions and local traffic behaviour, intersections with far distance to adjacent intersections (300m – 400m or > 400m) may not be effective. As was mentioned previously, the long stream between two intersections can accommodate a larger number of traffic movements, a larger number of vehicles in the same road capacity, higher speed, and longer queue length without direct impact on traffic congestion at the intersections. In this condition, it is important to evaluate the performance of ATCS including SCATS, at this kind of intersections.

If ATCS cannot improve the traffic performance, for examples increases traffic flow and decreases queue length at intersections or decreases travel time in the related streams, it means that the implementation of ATCS at this particular intersection is not effective. Therefore, let this particular intersection remain under Fixed Time traffic control system. Moreover, the decision regarding which intersections should be under ATCS can be more selective. This is also beneficial to reduce required financial support for ATCS implementation. On the other hand, if the ATCS has been applied, improvement to increase the traffic performance can be recommended. The recommended improvement will be discussed in detail in the following sections.

DATA COLLECTION

Field data was carried out in Bandung road network, Indonesia, including geometric detail, traffic demand, and traffic control data. Advanced traffic control system SCATS currently controls 117 signalised intersections out of 135 intersections in Bandung. The observed intersections in this research were 90 signalised intersections connected to SCATS, the other 27 signalised intersections were under flashing yellow signal because of changes in the direction of traffic [12].

The geometric detailed data was obtained from the Bandung road map, Bandung Area Traffic Control, Final System Design [8] and direct survey. The elements of this data include: lane width, number of lanes, medians, split islands, the dimension, location, and number of the loop detectors at each leg intersection, and the distance between intersections. This data was used to create a digitised Bandung road network map and to develop a simulated Bandung road network over the digitised network.

The traffic demand data was collected from data recorded by the SCATS system using a mini computer in the Bandung Traffic Control Room, and was also obtained from direct road observations when the road loop detectors were not available. Data collection was carried out from the 90 signalised intersections connected to SCATS in Bandung during morning peak (7:00 – 8:00 am), afternoon peak (4:30-5:30 pm) and off peak (10:00-11:00 am) periods. It was repeated every 15 minutes, including traffic flow data of each loop detector at each intersection, plus queue length data from a number of critical intersections with CCTV at each signalised intersection for vehicle detection. Whereas, the field travel time data was collected using floating car data in a number of streams based on road hierarchies. The survey was repeated between five to eight runs on three working days (Tuesday, Wednesday, and Thursday) during morning peak, off peak and afternoon peak periods. The data were used to validate the microscopic traffic simulation models and were not required as an input to develop the models.

The traffic control data including green time, amber time, all red time, cycle time, traffic direction, phases at each intersection, and possible turning movements for each lane were also required [12].

Two data sets were collected for use in this research. The first data set was used to develop and calibrate the models and the second data set was used for validation. The road network map of Bandung with intersections connected to and isolated from SCATS control is shown in Figure 1.

AIMSUN MICROSIMULATOR

The Generic Environment for Traffic Analysis and Modelling (GETRAM) was used as a tool to evaluate the performance of ATCS at intersections far from adjacent intersections in Bandung, Indonesia. GETRAM consists of TEDI as a traffic editor and AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non Urban Networks) as a microscopic traffic simulator [13, 14].

Previously, the Bandung microscopic traffic simulation models during peak and off peak periods have been developed, calibrated, and validated using GETRAM. Furthermore, a number of statistical tests including Paired T-test, Two Sample T-test, Regression Analysis, Analysis of Variance, and

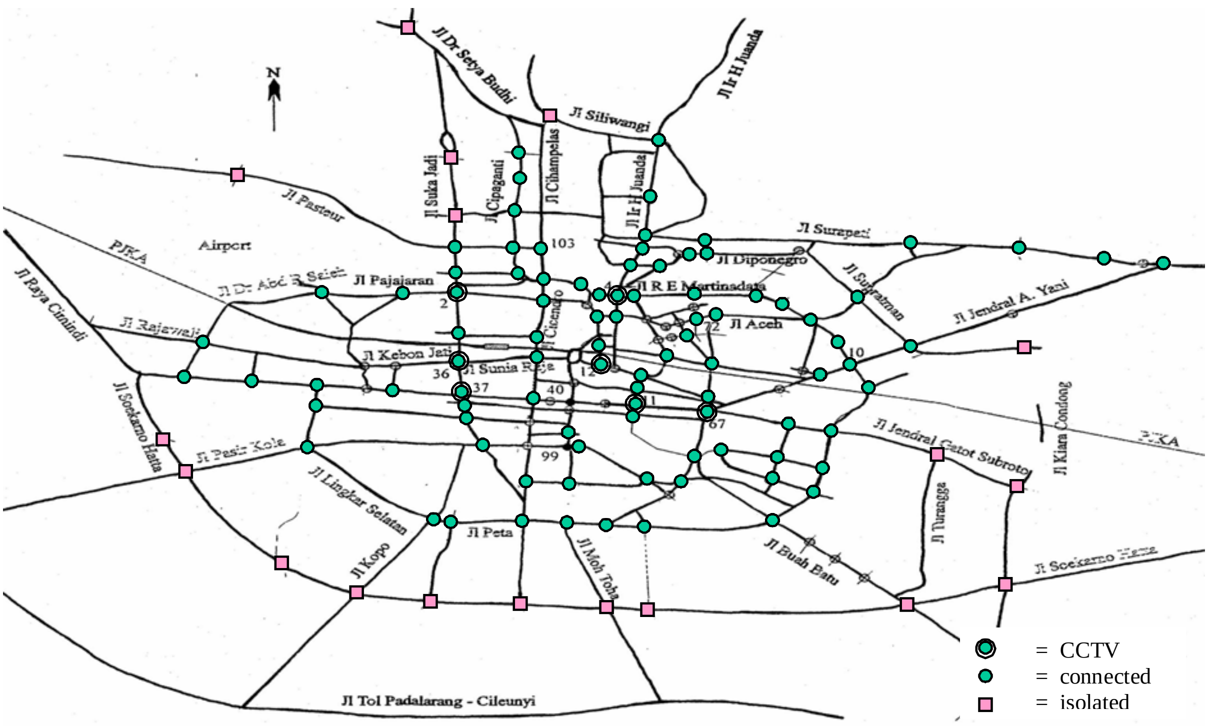

Figure 1. Signalised intersections in Bandung [7]

Correlation Tests [15, 16, 17] were used to determine the adequacy of the models in replicating traffic conditions. Based on the results of five statistical analyses, all of the calibrated and validated models reproduced traffic conditions with an acceptable degree of confidence. Therefore, the models were clearly accepted as significant valid replication of "the real world" [11, 18]. The validated models were then used to evaluate the performance of ATCS.

PERFORMANCE EVALUATION

Using the validated microscopic traffic simulation models, the results of comparative evaluation of the models with and without the application of ATCS can be obtained for the whole network. The traffic performance measures differences (%) between running the validated models under SCATS and under Fixed Time traffic control system of intersections far from adjacent intersections are presented in Table 1. Traffic performance measures used in this study are traffic flow (veh/h) and queue length (veh) at the intersections, and density (veh/km), speed (km/h), travel time (h:mm:ss), delay time (h:mm:ss), stop time (h:mm:ss), and number of stops per km (veh) in the streams. Table 1 shows that in general, SCATS performance was found to be worse than those under Fixed Time traffic control system.

IMPROVEMENT TO INCREASE TRAFFIC PERFORMANCE MEASURES

Since the performance of SCATS was found to be worse at intersections with greater distances between adjacent intersections, it is recommended to change these intersections from SCATS to a Fixed Time control if the following conditions are fulfilled

- a decrease in traffic flow was found at the intersection under SCATS;
- an increase in queue length was found at the intersection under SCATS;
- an increase in density, travel time, delay time, stop time, and number of stops in the stream containing the intersection, was found under SCATS;
- a decrease in speed in the stream containing the intersection was found under SCATS.

Therefore, the intersections that are recommended to be under Fixed Time control are intersections that performed worse in terms of all performance indicators under the SCATS traffic control system.

Again, using the validated microscopic traffic simulation models, the performance of SCATS at all signalised intersections as outputs from the validated models incorporating the recommended improvements can be obtained. Based on these, the performance differences (%) of signalised intersections far from adjacent intersections that were recommended under Fixed Time, and in the related streams are presented in Tables 2 and 3 and Figures 2 to 7.

The results in Tables 2 and 3 and Figures 2 to 7 clearly show that almost all of the performance measures at recommended intersections under the Fixed Time control were better than those under SCATS traffic control system as detailed below.
Table 2 shows that:

Table 1. Signalised intersections under SCATS that are recommended to be changed to Fixed Time control

INTERSECTION			Distance to adjacent intersection	Performance measures difference (%) under SCATS compare to under Fixed Time traffic control system									Change to Fixed Time traffic control system
No.	Node	Name		flow	q. length		density	speed	travel time	delay time	stop time	stops	
					mean ql	max ql							
1	19	Pasteur - Pasirkaliki	300 - 400 m	-6.91	34.72	1.69	7.44	9.27	10.75	15.77	18.29	-11.46	not recommended
2	42	A. Yani - Gudang Utara	300 - 400 m	-0.51	83.28	15.33	-10.12	5.01	-22.03	-22.88	-23.02	25.87	not recommended
3	59	Abdulrahman Saleh - Pajajaran	> 400 m	-3.82	-17.15	-5.39	-9.80	0.50	-0.55	-22.62	0.00	0.00	not recommended
4	89	Sukajadi - Eyckman	300 - 400 m	-4.55	6.21	4.30	-0.36	-0.96	21.23	45.79	55.79	-3.62	not recommended
5	91	Pasirkaliki - Kebon Kawung	> 400 m	-2.71	-5.91	-1.26	-0.36	-0.96	21.23	45.79	55.79	-3.62	not recommended
6	92	Kebon Kawung - Cicendo	> 400 m	-3.65	-10.60	-2.56	-18.09	2.93	-14.25	-23.50	-26.18	-12.11	not recommended
7	98	Cipaganti - Lamping	> 400 m	-2.70	117.89	45.97	-10.75	6.77	-6.36	12.75	45.81	-7.60	not recommended
8	99	Cipaganti - Sampurna	> 400 m	-5.96	820.01	144.14	-10.75	6.77	-6.36	12.75	45.81	-7.60	not recommended
9	100	Cipaganti - Eyckman	> 400 m	-5.33	63.02	34.70	-10.75	6.77	-6.36	12.75	45.81	-7.60	not recommended
10	120	Jawa - Sumatra	> 400 m	-5.15	-26.24	-4.36	-24.89	2.13	-4.97	-7.91	-10.41	-8.79	not recommended
11	46	Lingkar Selatan - Pagarsih	300 - 400 m	-0.49	70.33	25.82	19.68	-4.63	14.97	48.08	64.23	35.12	recommended
12	47	Pasirkoja - Jamika	> 400 m	-0.74	110.33	49.46	19.68	-4.63	14.97	48.08	64.23	35.12	recommended
13	50	Lingkar Selatan - Oto Iskandardinata	300 - 400 m	-2.75	173.52	59.91	6.79	2.07	4.48	12.32	18.17	-9.32	not recommended
14	51	Lingkar Selatan - Moh. Toha	300 - 400 m	-2.81	86.00	12.20	6.79	2.07	4.48	12.32	18.17	-9.32	not recommended
15	52	Lingkar Selatan - M. Ramdan	300 - 400 m	-6.59	72.54	32.95	6.79	2.07	4.48	12.32	18.17	-9.32	not recommended
16	53	Lingkar Selatan - Sriwijaya	> 400 m	-3.14	165.78	64.78	6.79	2.07	4.48	12.32	18.17	-9.32	not recommended
17	54	Lingkar Selatan - Buah Batu	> 400 m	-4.00	42.84	11.56	6.79	2.07	4.48	12.32	18.17	-9.32	not recommended
18	55	Lingkar Selatan - Martanegara	> 400 m	-9.90	-0.90	-1.12	32.43	-14.15	73.34	89.98	91.36	15.92	not recommended
19	56	Talaga Bodas - Lingkar Selatan	> 400 m	-8.41	0.14	11.09	32.43	-14.15	73.34	89.98	91.36	15.92	recommended
20	57	Lingkar Selatan - Gatot Subroto	> 400 m	-7.91	29.44	5.82	32.43	-14.15	73.34	89.98	91.36	15.92	recommended
21	70	Nurtanio - Rajawali	> 400 m	-0.25	20.67	16.11	0.42	0.08	0.00	0.00	0.00	0.00	not recommended
22	97	Gatot Subroto - Malabar	> 400 m	-8.43	290.54	60.90	22.12	1.62	-24.39	-37.95	-41.33	-15.60	not recommended
23	133	Palasari - Talaga Bodas	300 - 400 m	-20.17	753.39	195.59	37.37	-2.49	10.91	29.17	40.75	-17.00	not recommended
24	134	Oto Iskandardinata - Ciateul	300 - 400 m	-1.33	145.93	45.12	13.83	-2.87	22.46	143.52	224.23	34.47	recommended
25	135	Moh. Toha - Ciateul	300 - 400 m	-4.82	153.79	51.97	91.47	-8.98	74.85	276.20	367.69	19.65	recommended
26	136	Palasari - Lodaya	300 - 400 m	-25.41	35.51	16.86	36.95	-18.61	6.27	24.88	37.53	-19.45	not recommended

- Traffic flows at intersection 57 (Lingkar Selatan – Gatot Subroto) and intersection 135 (Moh. Toha – Ciateul) were found to be better under Fixed Time control i.e. 5.32% and 0.14%, respectively.
- Traffic flows at intersection 56 (Talaga Bodas–Lingkar Selatan) and intersection 134 (Otoiskandardinata–Ciateul) were found to decrease by 1.39% and 0.58%, respectively. These decreases are not significant.
- Traffic flows at intersection 46 (Lingkar Selatan–Pagarsih) and intersection 47 (Pasirkoja – Jamika) were found to decrease by 4.45% and 9.20%, respectively. In more detail, the decrease in traffic flow occurred especially during the morning peak period whereas during off peak and afternoon peak periods the traffic flow seemed similar.

While Table 3 shows that:

- Queue length at all recommended intersections were found to decrease between 7.70% and 63.17%.

Figures 2 to 7 show that:

Performance measures including density, speed, travel time, delay time, stop time and number of stop in the related streams were found to be better under Fixed Time control system. The streams are (1) Jamika North to South (2) Jamika South to North (3) Lingkar Selatan North to South, (4) Lingkar Selatan South to North (5) Oto Iskandardinata and (6) Moh. Toha.

EVALUATION OF IMPROVEMENTS

Since the performance of SCATS was found to be affected by distance between adjacent intersections, it was recommended to change these intersections under SCATS to Fixed Time control. The above results as outputs from the validated models incorporating the recommended improvements clearly indicated the following conclusions:

- Traffic flow at all recommended intersections under Fixed Time and under SCAT traffic control system seemed similar during off peak and afternoon peak periods.
- Not all of the intersection traffic flows during morning peak period indicated better performance. Part of intersection traffic flow during morning peak period was worse at a not significant level. The possible explanation for this is the traffic condition during morning peak period usually trends toward more congestion, therefore, Fixed Time or adaptive traffic control system can not help much to increase traffic performance. The other explanation is there is an influence of traffic conditions particularly from intersections and streams around the recommended intersections and related streams.
- On average, decreases in traffic flows at intersection 46 and intersection 47 were rather high i.e. 4.45% and 9.20%, respectively. However, other performance measures, for instance queue length at intersection 46 and intersection 47, and density, speed, travel time, delay time, stop time, and number of stops in related streams were much better.
- Mean queue length and maximum queue length at all recommended intersections under Fixed Time decreased between 7.70% and 63.17%.
- All performance measures i.e. density, speed, travel time, delay, stop time, and number of stops in related streams under Fixed Time were better than under SCATS traffic control.

Therefore, the intersections far from adjacent intersections under SCATS are recommended to be change to Fixed Time control, in order to increase the overall traffic performance. In other words, the application of SCATS at intersections far from adjacent intersections is not effective.

Table 2. Flow difference at signalized intersections which were recommended to be under Fixed Time

INTERSECTION			Distance to adjacent intersection	Flow difference (%)			
No.	Node	Name		morning peak	off peak	afternoon peak	average
1	46	Lingkar Selatan - Pagarsih	300 m - 400 m	-13.85	0.50	0.00	-4.45
2	47	Pasirkoja - Jamika	> 400 m	-28.54	1.04	-0.09	-9.20
3	56	Talaga Bodas - Lingkar Selatan	> 400 m	-5.39	1.04	0.17	-1.39
4	57	Lingkar Selatan - Gatot Subroto	> 400 m	14.75	0.22	0.98	5.32
5	134	Oto Iskandardinata - Ciateul	300 m - 400 m	-4.67	1.86	1.08	-0.58
6	135	Moh. Toha - Ciateul	300 m - 400 m	-1.23	0.95	0.71	0.14

Table 3. Queue length difference at signalized intersections which were recommended to be under Fixed Time

INTERSECTION			Distance to adjacent intersection	Queue Length difference (%)							
No.	Node	Name		morning peak		off peak		afternoon peak		average	
				mean ql	max ql	mean ql	max ql	mean ql	max ql	mean ql	max ql
1	46	Lingkar Selatan - Pagarsih	300 m - 400 m	-46.70	-19.70	-41.80	-27.30	-38.20	-18.50	-42.23	-21.83
2	47	Pasirkoja - Jamika	> 400 m	-64.10	-40.20	-55.60	-35.10	-52.80	-33.10	-57.50	-36.13
3	56	Talaga Bodas - Lingkar Selatan	> 400 m	-28.30	-16.50	-5.70	4.40	-11.20	-14.20	-15.07	-8.77
4	57	Lingkar Selatan - Gatot Subroto	> 400 m	-46.60	-10.20	20.80	-1.20	-41.70	-11.70	-22.50	-7.70
5	134	Oto Iskandardinata - Ciateul	300 m - 400 m	-63.50	-34.80	-62.50	-22.00	-63.50	-31.80	-63.17	-29.53
6	135	Moh. Toha - Ciateul	300 m - 400 m	-55.70	-29.40	-62.70	-27.50	-54.00	-31.60	-57.47	-29.50

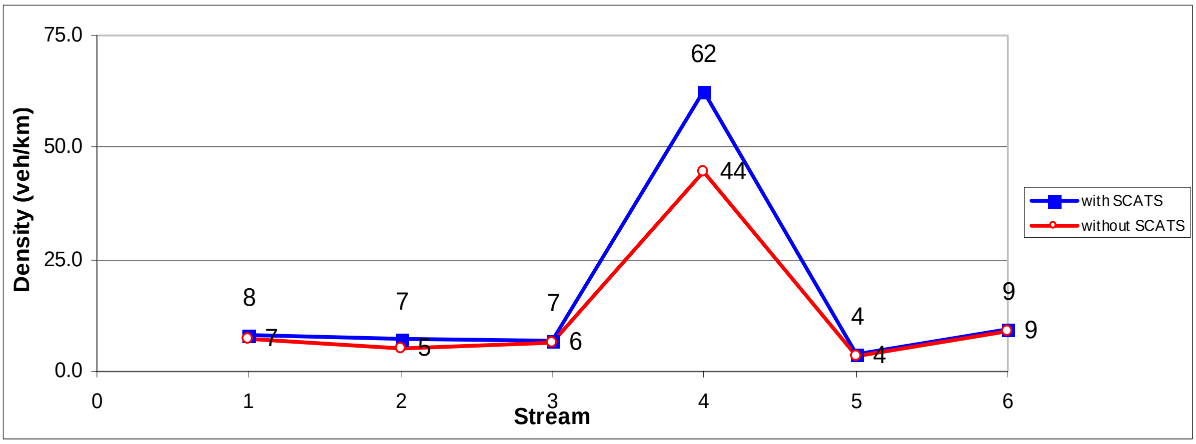

Figure 2. Density comparison between with and without SCATS

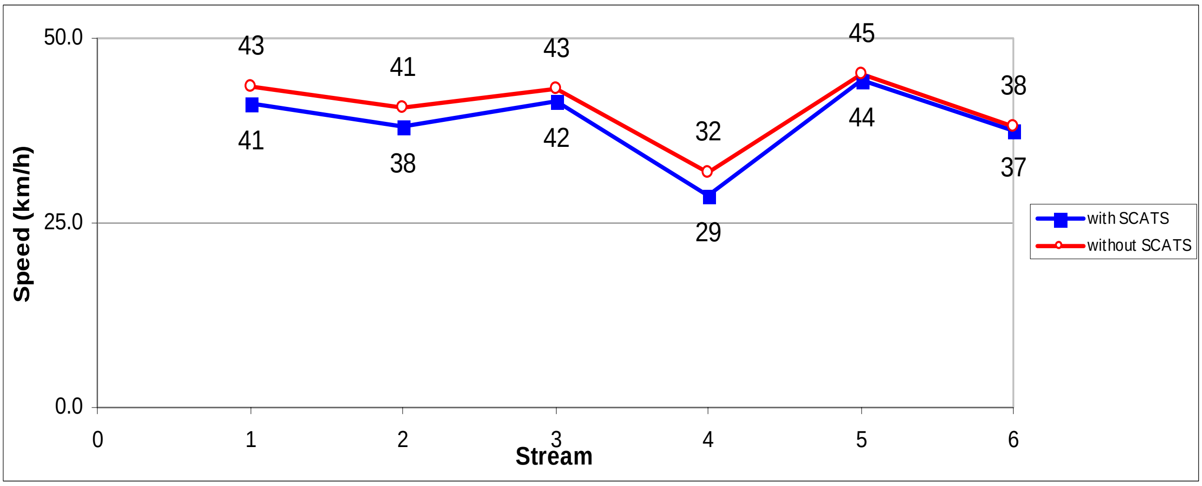

Figure 3. Speed comparison between with and without SCATS

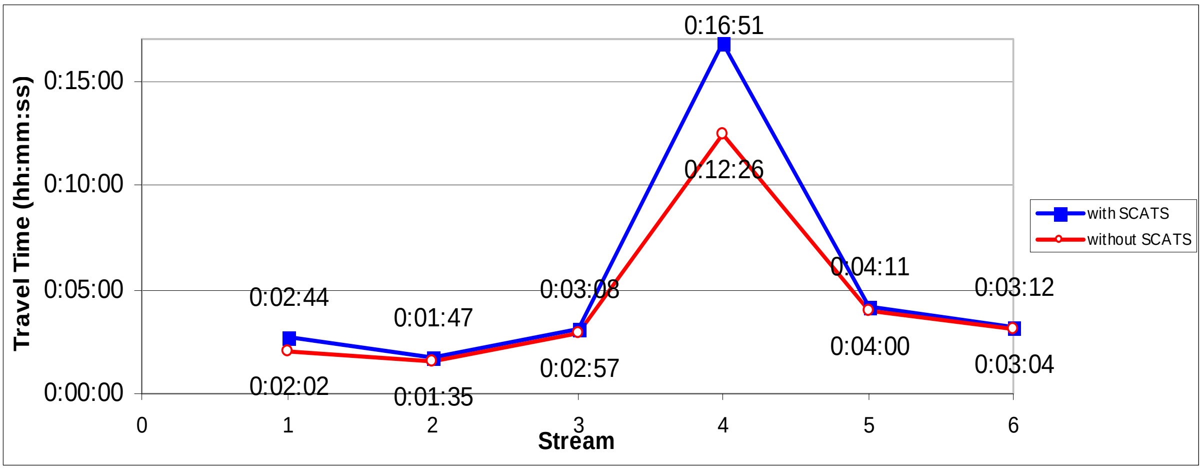

Figure 4. Travel Time comparison between with and without SCATS

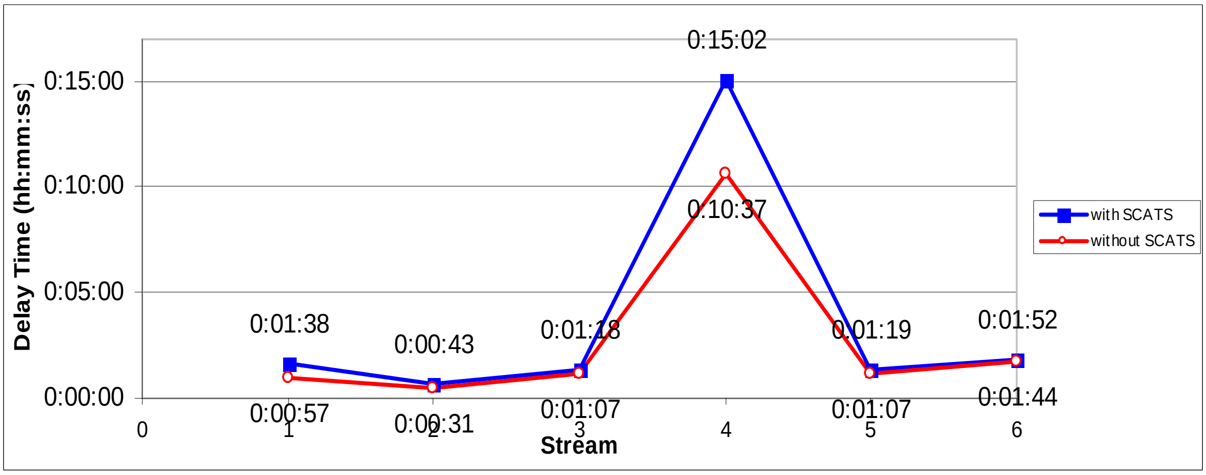

Figure 5. Delay Time comparison between with and without SCATS

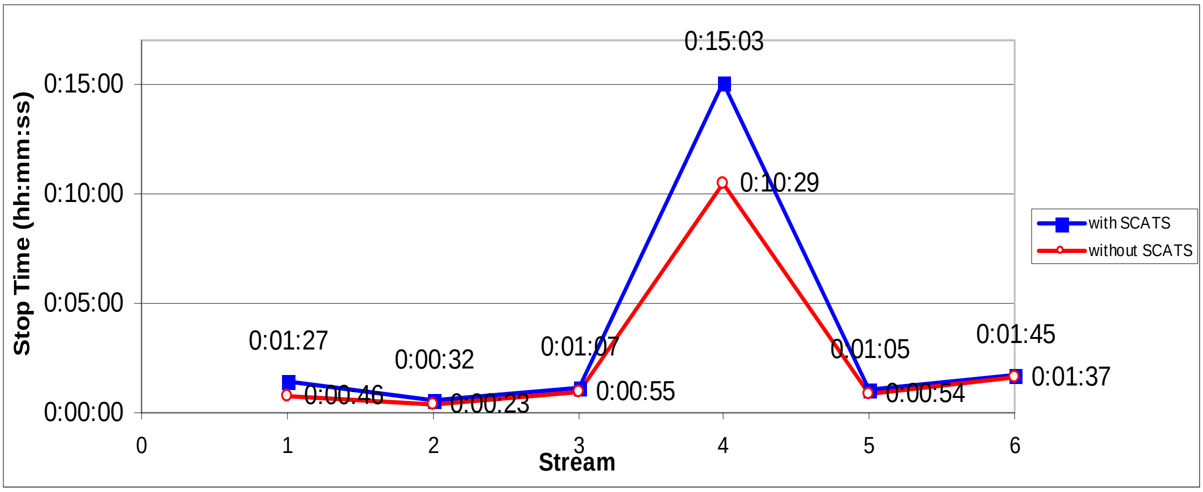

Figure 6. Stop Time comparison between with and without SCATS

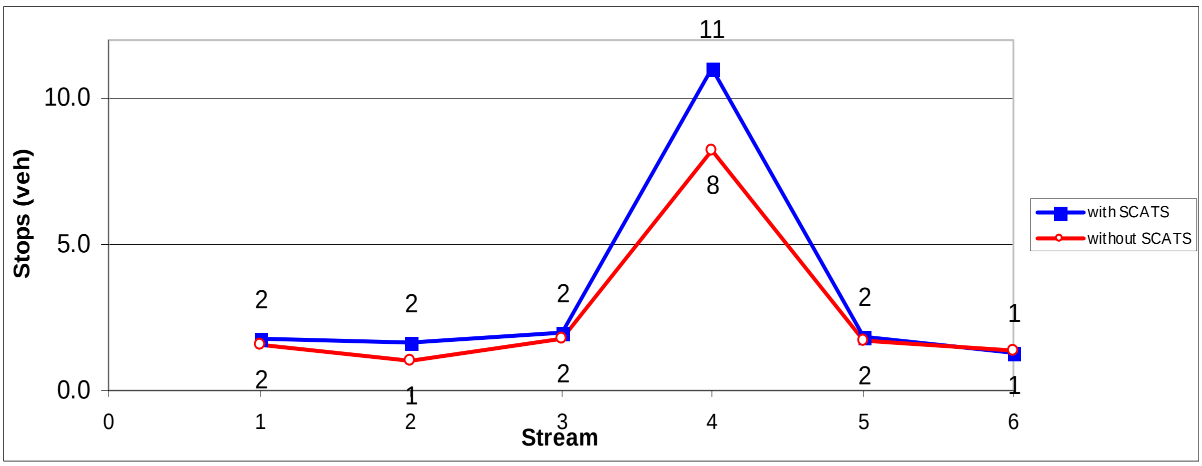

Figure 7. Number of stop comparison between with and without SCATS

CONCLUSIONS

This study evaluated the performance of advanced traffic control systems at signalised intersections far from adjacent intersections in a large city in a developing country that has a number of specific local conditions. AIMSUN micro simulator was used as a tool to evaluate the performance. The results presented in this paper clearly demonstrated that in general, traffic performance measures at intersections far from adjacent intersections were better under Fixed Time traffic control system than those under SCATS. In conclusion, the application of SCATS traffic control at intersections far from adjacent intersections is not effective. Therefore, in order to increase the overall traffic performance, the intersections far from adjacent intersections under SCATS are recommended to be under Fixed Time control if the certain conditions are fulfilled. The findings of this study are believed to be applicable not only to Bandung, but also beneficial for other large cities in Indonesia and other developing countries that have similar specific local conditions.

REFERENCES

1. Sinha, K.C., Can Technologies Cure Transportation Ills?, *Proceedings of the Sixth International Conference on Application of Advance Technology in Transportation Engineering* Singapore, 2000.

2. U.S. Department of Transportation, *Benefit of Integrated Technologies and The National ITS Architecture* [online] available from http://www.its.dot.gov/its_overview 2005.

3. ITS Australia, *Intelligent Transportation System Australia* [online] available from http://www.its-australia.com.au/ 2005.

4. Luk, JYK., *Queue Management and Monitoring in Urban Traffic Control Systems, Working Document no. WD TE 92/002*, Australian Road Research Boards, 1992.

5. Giannakodakis, G., *The Strategic Application of Intelligent Transport Systems ITS, Technical Note, Road and Transport Research*, Volume 4, no. 4, pp. 56-63, 1995.

6. PATH, ITS, The Intelligent Transportation Systems Decision Support System Web site [online] available from *http://www.path.berkeley.edu/ Signal Control Systems*, 2005.

7. Plessey, AWA, *Bandung Area Traffic Control, SCATS Presentation and "Before" Traffic Study Details,* Directorate General of Land Transport, Ministry of Communications, Government of Republic of Indonesia, 1996.

8. Plessey, AWA, *Bandung Area Traffic Control, Final System Design*, Directorate General of Land Transport, Ministry of Communications, Government of Republic of Indonesia, 1996.

9. Ogden, K.W., Taylor, S.Y., *Traffic Engineering and Management,* Institute of Transport Studies, Department of Civil Engineering, Monash University, Clayton Vic 3168, Australia, 1999.

10. Morichi, S., Long-term Strategy for Transport System in Asian Megacities, *Proceeding of the 6th Eastern Asia Society for Transportation Studies International Conference in Bangkok, Thailand*, September 2005, pp. 1–21.

11. Sutandi., A. C., Dia, H., Performance Evaluation of An Advance Traffic Control Systems in A Developing Country, *Proceedings of the 6th Eastern Asia Society for Transportation Studies International Conference in Bangkok*, Thailand, September 2005, pp. 1572 – 1584.

12. Sutandi, A. C., *Performance Evaluation of Advanced Traffic Control Systems In A Developing Country,* Ph. D Dissertation (The University of Queensland, Brisbane, Australia), 2006.

13. TSS, *Transport Simulation Systems*, available from http://www.tss-bcn.com , 2004.

14. TSS, *GETRAM Manual, Open Traffic Simulation Environment*, February 2004, available from http://www.aimsun.com/v4.2/Manual.zip, 2004.

15. Mason, R. L., Gunst, R. F., Hess, J. L., *Statistical Design and Analysis of Experiments with Applications of Engineering and Science*, 2nd edition, John Willey and Sons Hoboken, New Jersey, 2003.

16. Montgomery, D. C., Runger, G. C., *Applied Statistics and Probability for Engineers*, 3rd edition, John Wiley and Sons, Inc., 2003.

17. Ott, R. L., Longnecker, M., *An Introduction to Statistical Methods and Data Analysis*, 5th edition, Duxbury 511 Forest Lodge Road Pacific Grove, CA 93950, USA, 2001.

18. Sutandi, A. C., Dia, H. D., Evaluation of the Impacts of Traffic Signal Control Parameters on Network Performance, *the 27th Conference of the Australian Institutes of Transport Research,* December 2005, Queensland University of Technology, Brisbane, Australia, 2005.