RELATIONSHIP BETWEEN TRAFFIC PERFORMANCE MEASURES AND SIGNIFICANT VARIABLES WHICH INFLUENCE THE PERFORMANCE OF ATCS

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ABSTRACT

Advanced Traffic Control Systems (ATCS) are recognised as one of ITS (Intelligent Transportation Systems) technologies that have most potential to ease congestion problems in many large cities in developing countries. The application of ATCS in developing countries is unique because cities in developing countries face more severe transportation problems than those in developed countries and characterised by specific geometric and traffic local conditions, for examples: low road network densities with poor conditions, narrow lane width, poor lane discipline, and level of side friction in connection with on street parking and street vendor activities. A large road network under ATCS surveillance in Bandung, Indonesia was used as a case study. This study identified a large number of influencing factors which were then used as input variables to determine their impact on the performance of an ATCS. Multiple regression analysis was used to investigate relationships between traffic performance measures i.e. throughput, queue length, and travel time, and these significant variables. High technology built in a developed country can be successfully implemented in a developing country if the specific geometric and traffic conditions in the large cities and the local traffic behaviour are taken into account. By finding out the relationships between traffic performance measures and the significant variables, appropriate improvements of the performance of the ATCS in large city in developing country can be recommended. The findings of this study are believed not only beneficial to improve ATCS performance and reduce traffic congestion in Bandung, but also beneficial for other large cities in Indonesia and other developing countries, that has similar specific local conditions.

Keywords: ATCS, specific geometric, traffic conditions, and traffic performance measures.

INTRODUCTION

Traffic congestion is a complex problem in many large cities around the world, including in developing counties. Road authorities have now recognised that building additional road capacity alone does not help to solve traffic congestion. More emphasis is being placed recently on travel demand management techniques and the application of advanced technologies such as Advanced Traffic Control Systems (ATCS) to improve efficiency and capacity of existing road infrastructure (US DOT, 2005, ITS Australia, 2005).

The application of such systems in developing countries posed unique challenges because these cities faced more severe transportation problems and are characterised by low road network densities (Morichi, 2005) with narrow lanes, poor lane discipline, and level of side friction in connection with on street parking and street vendor activities (Sutandi and Dia, 2005a, 2005b). The aim of this study is to identify a number of significant variables which influence the performance of ATCS.

Multiple regression analysis was then used to investigate relationships between traffic performance measures i.e. throughput, queue length, and travel time, and significant variables. The evaluation of traffic performance measures were obtained in this study using traffic simulation AIMSUN (Advanced Interactive Microscopic Simulation for Urban and Un-urban Network). By finding out the relationships between traffic performance measures and the significant variables, appropriate improvements in the performance of the ATCS can be recommended, based on the existing specific geometric and traffic conditions and the specific local traffic behaviour.

Road network in Bandung, Indonesia was used as a case study. Advanced traffic control system SCATS (Sydney Co-ordinated Adaptive Traffic System) was implemented in this city in June 1997 as a pilot project. SCATS currently controls 117 signalised intersections out of 135 intersections in Bandung (Awa Plessey, 1996a). The observed intersections in this research were the 90 signalised intersections connected to SCATS, wherein the other 27 signalised intersections were under flashing yellow signal.

Traffic Performance Measures and Variables

The traffic performance measures used in this study are throughput (veh/h) and queue length (veh) at signalised intersections and travel time (hh:mm:ss) in the "stream". A stream is a set of sections that are consecutive and connected through intersection (TSS, 2004a). All of the streams are divided based on the road hierarchy.

The variables that might have significant influence on the performance measures at intersections can be classified into the following three categories:

- variables that include in the geometric and traffic conditions of intersections including number of leg intersections, number of medians, number of splitter islands, number of phases, number of movements, the size of intersection, the existence of CCTV, the longest width of leg intersection, and the shortest width of leg intersection.
- variables that include in the geometric and traffic conditions of the road network including the distance to the closest intersection, the road hierarchy, volume capacity ratio of major road, and volume capacity ratio of minor road.
- other variables, regarding the specific local conditions in the large city Bandung including the presence of policemen at intersection which encourage people to adhere the traffic regulation, the location of intersection (in CBD or in residential area), and level of side friction, in connection with on street parking and on street vendor activities.

Whereas the variables that might have significant influence on the performance measures in the streams can be classified into the following three categories:

- variables that include in the geometric and traffic conditions of intersections along the stream including the distance to the closest intersection, number of phases at intersection, and the existence of CCTV at intersection.
- variables that include in the geometric and traffic conditions of the stream including the road hierarchy, lane width, and number of lanes, volume capacity of the road.
- other variables, regarding the specific local conditions in the large city, Bandung including the presence of policemen at intersection which encourage people to adhere the traffic regulation, the location of intersection (in CBD or in residential area), and level of side friction, in connection with on street parking and on street vendor activities (Sutandi and Dia, 2005b).

RESEARCH METHOD

AIMSUN Microsimulator

GETRAM (The Generic Environment for Traffic Analysis and Modelling) was used as a tool to evaluate the traffic performance measures in Bandung road network, 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 (TSS, 2004a, TSS, 2004b).

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 Correlation Tests (Mason, Robert L. et al., 2003, Montgomery, Douglas C., and Runger, George C., 2003, Ott, R. Lyman, and Longnecker, Michael, 2001) 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" (Sutandi and Dia, 2005a, 2005b). The validated models were then used to evaluate the traffic performance measures in Bandung.

Data Collection

Field data was carried out in a large road network area in Bandung, Indonesia including geometric detail data, traffic demand data, and traffic control data. Advanced traffic control system SCATS (Sydney Coordinated Adaptive Traffic Control Systems) currently controls 117 signalised intersections out of 135 intersections in Bandung. The observed intersections in this research were the 90 signalised intersections connected to SCATS, wherein the other 27 signalised intersections were under flashing yellow signal because of changes to the direction of traffic (Sutandi, 2006).

The geometric detailed data was obtained from the Bandung road map, Bandung Area Traffic Control, Final System Design (AWA Plessey, 1996b) and direct survey. The elements of this data include: lane width, number of lanes, medians, splitter islands, the dimension, location, and number of the loop detectors at each leg intersection, and also 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. Direct road observations were also needed when the road loop detectors were not available and to obtain existence of policemen at intersection. 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 throughput data of each loop detector at each

phases at each intersection, and possible turning movements for each lane were also required (Sutandi, 2006) .

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.

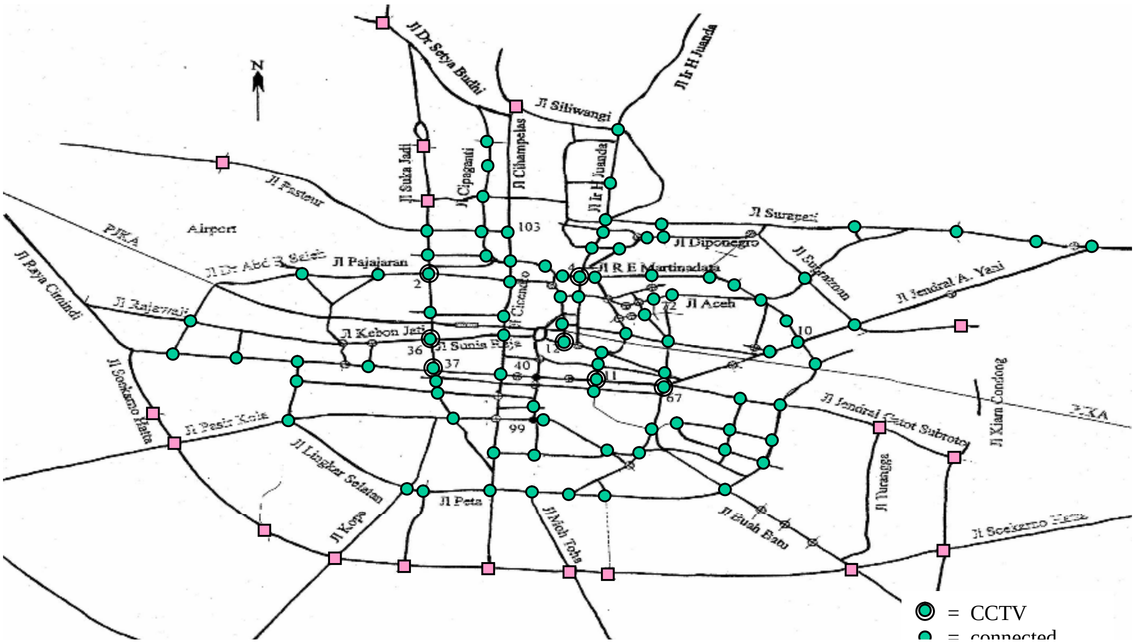

Figure 1 Map of Signalised Intersections Connected to and Isolated from SCATS in Bandung, Indonesia (AWA Plessey, 1996)

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 was used to validate the microscopic traffic simulation models and was 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,

Multiple Regression Analysis

Multiple Regression Analysis is used to describe the relationship between the traffic performance measure and the variables that influence the performance of SCATS. This method is also used to determine a set of significant variables that have strong relationships on SCATS performance. The multiple regression equations are such as follow:

$$\mathbf{Y_{int} = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16})} \quad \ldots\ldots\ldots(1)$$

with,

Y_{int} = the performance measures at intersection
X_1 = number of leg intersections
X_2 = number of medians
X_3 = number of splitter islands
X_4 = number of phases
X_5 = number of movements
X_6 = the size of intersection (mean approach width: (1) = large, > 9m ; (2) = medium, 6m - 9m ; (3) = small, 3m-6m)
X_7 = the existence of CCTV ((1) = no ; (2) = yes)
X_8 = presence of enforcement at intersection ((1) = no ; (2) = yes)
X_9 = the location of intersection ((1) = CBD ; (2) = RES)
X_{10} = the distance to the closest intersection ((1) = < 100m ;(2) = 100m – 200m ; (3) = 200m - 300m ; (4) = 300m - 400m ; (5) = > 400m)
X_{11} = road hierarchy ((1) = local road; (2) = secondary collector road ; (3) = primary collector road ; (4) = secondary arterial road ; (5) = primary arterial road)
X_{12} = the longest width of leg intersection
X_{13} = the shortest width of leg intersection
X_{14} = volume capacity ratio of major road
X_{15} = volume capacity ratio of minor road
X_{16}= level of side friction ((1) = high; (2) = low)

$$\mathbf{Y_{stream} = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10})} \quad \ldots\ldots\ldots\ldots..(2)$$

with,

Y_{stream} = the performance measures in the stream
X_1 = the location of the road ((1) = CBD ; (2) = RES)
X_2 = road hierarchy ((1) = local road ; (2) = secondary collector road ; (3) = primary collector road ; (4) = secondary arterial road ; (5) = primary arterial road)
X_3 = lane width (m)
X_4 = number of lanes
X_5 = the distance to the closest intersection ((1) = < 100m ; (2) = 100m – 200m ; (3) = 200m - 300m ; (4) = 300m - 400m ; (5) = > 400m)
X_6 = volume capacity ratio of the road
X_7 = level of side friction ((1) = high ; (2) = low)
X_8 = average number of phases
X_9 = the percentage of intersection with CCTV
X_{10} = the percentage of intersection with existence of policemen

The traffic performance measures $\mathbf{Y_{int}}$ (throughput and queue length) and $\mathbf{Y_{stream}}$ (travel time) were obtained from the validated microscopic traffic simulation model whereas the geometric and traffic conditions as the independent variables were the observed field data.

Multiple regression analysis is carried out during morning peak, off peak and afternoon peak periods for both regions in Bandung, the Bandung North Region and the Bandung South Region.

RESULTS AND DISCUSSION

The results of multiple regression analysis during
morning peak and off peak periods are presented in Table 1 – 2 below (Sutandi, 2006).

The further analysis were undertaken **only** to the results of multiple regression analysis that have the value of **adjusted square R (R^2) more than 0.5** and the value of Durbin Watson residual test between 1.5 and 2.5 (Lyman Ott, 2001, Dillon et. all, 1984, and Pfaffenberger et. all, 1981). Therefore, the set of variables have not only strong relationship to the performance measures but also significant ability to estimate the real condition of the performance measures.

Further Analysis Regarding The Influence Of Significant Variables On The Performance of SCATS

With respect to the application of a system such as the SCATS, the analysis in this section is very crucial. High technology built in a developed country can be successfully implemented in a developing country if the specific geometric and traffic conditions there and the local traffic behaviour are taken into account.

The results of Multiple Regression Analysis that were presented in Table 1 – 2 above (with the value of R^2 more than 0.5 and the value of Durbin Watson residual test between 1.5 and 2.5) clearly showed that the performance of SCATS is positively influenced by the local specific geometric conditions and local traffic behaviour in the city, and therefore the detail explanation of the relationships should also based on the specific local conditions.

Based on these results and based on existing geometric and traffic behaviour in Bandung, the further analysis found that in Bandung North Region:

- Throughput was found to increase at intersection with higher v/c ratio of major road, larger size of intersection, and the presence of policemen. Poor lane discipline of the drivers in Bandung causes the traffic condition trend towards congestion during peak and off peak periods. Lane discipline of the drivers will increase v/c ratio of the road and therefore, also increase the throughput at intersection. Larger size of intersection has wider leg intersection with higher road capacity that might increase throughput. Moreover, larger size of intersection provides a space for vehicles that pass the intersection during amber time period before the following platoon enter the intersection. In North Region, most intersections with the presence of policemen at intersection have high v/c ratio. In more detail, 9 out of 15 (60 %) intersections with the presence of policemen have the value of v/c > 0.8, and 14 out of 15 (93 %) intersections with the presence of policemen have the value of v/c > 0.5. The drivers usually have poor lane discipline and often pass an intersection during amber time period. At intersection with very congested traffic condition, this behaviour cause more traffic congestion. But, the presence of policemen at intersection will encourage people to adhere to the traffic regulations. Therefore, at intersections with high v/c ratio, the presence of policemen will increase throughput at intersection.

Table 1. The results of Multiple Regression Analysis between performance measures and significant variables during morning peak (MP), off peak (OP), and afternoon peak (AP) periods in Bandung North Region

y	**R**	**Adjusted R^2**	**d**
$y_{MPN\ throughput} = 1880.106 + 1718.060\ x_{14} - 460.745\ x_6 - 274.561\ x_3 + 454.678\ x_8 - 258.095\ x_4$ x_{14} = v/c ratio of major road x_6 = the size of intersection x_3 = number of splitter islands x_8 = the presence of policemen x_4 = number of phases	0.815	**0.624**	**2.121**
$y_{MPN\ mean\ ql} = -110.357 + 7.218\ x_{12} - 19.098\ x_3 + 33.030\ x_8$	0.661	0.398	2.180
$y_{MPN\ max\ ql} = -113.245 + 8.355\ x_{12} - 25.384\ x_3 + 42.034\ x_8$	0.688	0.437	2.047
$y_{MPN\ travel\ time} = 1.238E-02 + 1.770E-04\ x_{10} - 6.060E-03\ x_4$	0.551	0.250	1.362
$y_{OPN\ throughput} = 1699.504 - 394.995\ x_6 + 842.227\ x_{14} - 352.543\ x_3 + 588.413\ x_8$ x_6 = the size of intersection x_{14} = v/c ratio of major road x_3 = number of splitter islands x_8 = the presence of policemen	0.796	**0.600**	**1.965**
$y_{OPN\ mean\ ql} = -19.099 + 30.275\ x_8 - 14.080\ x_3 + 15.701\ x_4 - 41.091\ x_7$	0.728	0.486	2.156
$y_{OPN\ max\ ql} = -15.902 + 37.735\ x_8 - 20.753\ x_3 + 20.505\ x_4 - 44.776\ x_7$ x_8 = the presence of policemen x_3 = number of splitter islands x_4 = number of phases x_7 = the existence of CCTV	0.754	**0.528**	**2.192**
$y_{OPN\ travel\ time}$ = -	-	-	-
$y_{APN\ throughput} = 2877.695 + 1932.438\ x_{14} - 628.142\ x_6 - 322.137\ x_3 - 64.323\ x_{12}$ x_{14} = v/c ratio of major road x_6 = the size of intersection x_3 = number of splitter islands x_{12} = the longest width of leg int	0.817	**0.637**	**1.784**
$y_{APN\ mean\ ql} = -86.767 + 8.828\ x_{12} - 14.059\ x_3$	0.593	0.323	1.903
$y_{APN\ max\ ql} = -85.293 + 6.913\ x_{12} - 25.182\ x_3 + 17.625\ x_4$	0.653	0.387	1.998
$y_{APN\ travel\ time}$ = -	-	-	-

Table 2. The results of Multiple Regression Analysis between performance measures and significant variables during morning peak (MP), off peak (OP), and afternoon peak (AP) periods in Bandung South Region

y	R	Adjusted R^2	d
$y_{MPSthroughput} = 2755.226 + 1156.426\ x_{14} + 913.851\ x_7 - 611.384\ x_6 - 498.802 x_8 - 202.048\ x_{10}$ x_{14} = v/c ratio of major road x_7 = the existence of CCTV x_6 = the size of intersection x_8 = the presence of policemen x_{10} = the distance to the closest int	0.886	**0.754**	**1.680**
$y_{MPS\ mean\ ql}$ = -	-	-	-
$y_{MPS\ max\ ql}$ = -	-	-	-
$y_{MPS\ travel\ time}$ = -	-	-	-
$y_{OPS\ throughput} = 2150.293 + 2646.944\ x_{14} - 267.174\ x_4 - 480.369\ x_6 - 127.939\ x_{10} + 533.240\ x_7 - 88.699\ x_{11}$ x_{14} = v/c ratio of major road x_4 = number of phases x_6 = the size of intersection x_{10} = the distance to the closest int x_7 = the existence of CCTV x_{11} = road hierarchy	0.948	**0.881**	**2.475**
$y_{OPS\ mean\ ql} = -43.530 + 37.098\ x_9 - 13.847\ x_2 + 4.605\ x_5$	0.610	0.323	2.166
$y_{OPS\ max\ ql} = -29.575 + 37.251\ x_9 - 15.314\ x_2 + 5.172\ x_5$	0.602	0.312	2.275
$y_{OPS\ travel\ time}$ = -	-	-	-
$y_{APS\ throughput} = 2330.848 + 1563.232\ x_{14} - 106.771\ x_5 - 173.492\ x_{11} - 410.815\ x_6 - 673.972\ x_7$ x_{14} = v/c ratio of major road x_5 = number of movements x_{11} = road hierarchy x_6 = the size of intersection x_7 = the existence of CCTV	0.898	**0.779**	**2.368**
$y_{APS\ mean\ ql}$ = -	-	-	-
$y_{APS\ max\ ql} = 16.698 + 28.486\ x_{15}$	0.324	0.083	1.713
$y_{APS\ travel\ time}$ = -	-	-	-

- Throughput was found to decrease at intersection with higher number of splitter islands, higher number of phases, and the longest width of leg intersection. Splitter islands force the drivers to queue in the proper lane. The vehicles that want to go straight cannot queue in the LTOR (left turn on red) lane. This condition decrease throughput at intersection. This is one of specific local conditions in Bandung. Higher number of phases needs more time to get back to the same phase in order to produce throughput during the green time period. This condition decrease throughput at intersection. At intersection in Bandung, traffic condition on leg intersection with the longest width usually very congested because they lie on the road with higher road hierarchy. In order to increase throughput and reduce the very congested traffic condition, wider width of the leg is needed.

- Max queue length was found to decrease at intersection with higher number of splitter islands and at intersection under CCTV surveillance during off peak period. Splitter islands force the drivers to queue in the proper lane. In this condition, vehicles that want to go straight queue in the middle lane and provide (not block) the vehicles that queue in the LTOR lane to turn left. This condition reduces queue length at intersection. Field data from

CCTV is one of the input data for SCATS traffic control system to determine the green time that can reduce the queue length.

- Max queue length was found to increase at intersection with the presence of policemen and higher number of phases during off peak period. The presence of policemen at intersection will encourage people to adhere to the traffic regulations, for example, not pass the intersection during amber time period. This condition increases queue length at intersection. Higher number of phases needs more time to get back to the same phase in order to produce throughput during the green time period. This condition will increase queue length at intersection.

Whereas in Bandung South Region it was found that:

- Throughput was found to increase at intersection with higher v/c ratio of major road, under CCTV surveillance, and larger size of intersection. Similar to the Bandung North Region condition, poor lane discipline of the drivers causes the traffic condition trend towards congestion during peak and off peak periods. Lane discipline of the drivers will increase v/c ratio of the road and therefore, also increase the throughput at intersection. Field data from CCTV is one of the input data of SCATS traffic control system to determine green time period that can increase throughput. The condition could occur because intersection under CCTV surveillance in Bandung South Region was not in a congested or over saturated traffic conditions. In saturated traffic condition, the presence of CCTV or adaptive traffic control system cannot help to increase traffic performance. Larger size of intersection has wider leg intersection with higher road capacity that might increase throughput. Moreover, larger size of intersection provides a space for vehicles that pass the intersection during amber time period before the following platoon enter the intersection.

- Throughput was found to decrease at intersection with farther distance to the adjacent intersection, higher road hierarchy, the presence of policemen, higher number of phases, and higher number of movements. The application of SCATS was not effective at intersections with far distance to the adjacent intersection because long stream between 2 intersections can accommodate larger number of traffic movements, larger number of vehicles in the same road capacity, higher speed, and longer queue length at intersection without direct impact to the traffic congestion at intersection. In these conditions adaptive traffic control system SCAT cannot significantly increase traffic performance, therefore performance of SCATS was better at intersections with close distance to adjacent intersection. The performance of SCATS was worse at intersections along the stream with higher road hierarchy that usually very congested. In this condition the presence of adaptive traffic control system cannot increase traffic performance. In South Region, most intersections with the presence of policemen at intersection have moderate or low v/c ratio. In more detail, 2 out of 14 (14 %) intersections with the presence of policemen have the value of v/c > 0.8, and 9 out of 14 (64 %) intersections with the presence of policemen have the value of v/c > 0.5. The drivers usually have poor lane discipline and often pass the intersection during amber time. At intersection with moderate or low v/c ratio, pass the intersection during amber time will increase throughput at intersection. The presence of policemen at intersection will encourage people to adhere to the traffic regulations, for example not pass the intersection during amber time. Therefore, at intersection with moderate or low v/c ratio, the presence of policemen will decrease throughput at intersection. This is one of the local specific conditions in a large city in a developing country. Higher number of phases and movements needs more time to get back to the same phase and movement in order to produce throughput during the green time period. This condition decrease throughput at intersection.

Based on these significant variables, appropriate improvements to increase the performance of SCATS traffic control system can be recommended.

Substantial Improvements

The following substantial improvements to increase the performance of SCATS, are recommended based on the significant variables that have not only strong relationship but also significant ability to estimate the real condition of the performance measures. The improvements are also recommended based on the local conditions in the large city in developing country, in this case Bandung, in order to be realistic for application.

The recommended improvements to SCATS fall into the following three categories:

1. Recommended improvements that can be implemented physically.
2. Recommended improvements to encourage drivers to adhere to traffic regulations.
3. In addition to the two categories of recommended improvements, there are a number of variables that also have strong relationships and significant ability to estimate real performance and improve the performance of SCATS, but are difficult to apply.

1 Recommended improvements that can be implemented physically

The substantial improvements to increase the performance of SCATS are such as follow:

- Since higher number of phases and higher number of movements were found to decrease in throughput and increase in queue length at intersections, it was recommended to restrict the number of movements at intersection. The movement from the road with lower road hierarchy was prohibited to enter the road with higher hierarchy but the movement from higher hierarchy road was permitted to enter the lower hierarchy road. The choice of intersections to be recommended for restrictions in number of phases and movements should be taken seriously into account. Intersections are chosen for a number of reasons as discussed below:

  - the intersection is in the middle of the stream
  - the stream has a number of intersections
  - the intersection has many movements (> 10 movements)
  - there are other ways to enter the road with higher hierarchy
  - the intersection is crossroad between different road hierarchies that usually more congested

- In the longest width of leg at intersections in Bandung, it was found to decrease in throughput because these legs have lain on the road with higher road hierarchy that usually very congested. Higher road hierarchy was also found to decrease in throughput. Another analysis result indicated that larger size of intersection that certainly had wider width of leg at intersection was found to increase in throughput. However, building wider leg intersection or additional road capacity physically has a number of challenges, particularly in large city in developing country that has high population density, limited land area and limited financial support. Furthermore, building additional road capacity is not the right solution to increase the performance of SCATS. Based on the condition, in order to increase throughput at intersection, it was recommended to make the width of leg intersection wider by changing two-way road into one-way road if there was an alternative road with the same hierarchy to accommodate vehicles from the changed direction. The one-way road not only caused the leg wider but also reduced number of phases and number of movements at intersection.

- Since the performance of SCATS was found worse at intersections with far distance (300m-400m, > 400m) between adjacent intersections, it was recommended to change these intersections under SCATS to be under Fixed Time traffic control system. The intersections that were recommended to be under Fixed Time traffic control system were intersections that had worse performance for all performance measures under SCATS traffic control system. The performance measures including throughput and queue length at intersections and density, speed, travel time, delay time, stop time and number of stops in the streams, as the output of the models.

2 Recommended improvements in order to encourage drivers to adhere to the traffic regulation are as follows:

- Lane discipline of drivers will increase v/c ratio of the road and therefore increase throughput at intersections. Since intersections with high v/c ratio of the major road were found have increased throughput, efforts should therefore be made to encourage people to adhere to the traffic regulations, in particular, to lane discipline.

- Since the presence of policemen at intersections was found to increase throughput, the presence of policemen at intersections is still needed to encourage people to adhere to the traffic regulations.

3 Variables that have strong relationship to the performance measures in increasing the performance of SCATS, but are difficult to apply. The variables are as follow:

- ❖ Larger size of intersection was found to increase throughput at intersection, but as was previously mentioned, building additional road capacity has a number of challenges, particularly in a large city in a developing country that has high population density, limited land area and limited financial support. Moreover, building additional road capacity is not the right solution to increase the performance of SCATS. Larger sizes of intersections (that certainly has wider width of leg) were found to increase throughput. Wider width of leg intersection can be achieved by changing two-way roads into one-way roads, as was recommended previously.

- ❖ Higher number of splitter islands was found to decrease throughput at intersections because they force the drivers to queue in the proper lane. The vehicles that want to go straight cannot queue in the LTOR (left turn on red) lane. This decreases throughput at intersections, however the existence of splitter islands has to be maintained to encourage people to queue in the proper lane.

CONCLUSIONS

This study evaluated the relationships between the traffic performance measures and the significant variables that influence the performance of advanced traffic control system SCATS in Bandung during peak and off peak periods. The variables that might have significant influence on the performance measures are classified into three categories: variables related to the geometric and traffic conditions of intersections, variables related to the geometric and traffic conditions of the road network and variables related to the specific local conditions in the large city, for example traffic behaviour. The traffic performance measures were obtained from the validated microscopic traffic simulation models, whereas the geometric and traffic conditions as independent variables were the observed field data. Multiple regression analysis was used to describe the relationship between the traffic performance measure and the selected set of variables and to determine the significant variables that influence the performance of SCATS. The results of multiple regression analysis that were discussed above clearly showed that the performance of SCATS is positively influenced by the local specific geometric conditions and local traffic behaviour in the city. The recommended improvements to increase the performance of SCATS should be based on the significant variables and based on specific local conditions in order to be realistic in application, for instances: restriction in number of phases and movements, changing two-way road into one-way if there is alternative road, change intersections far from adjacent intersection under SCATS to be under Fixed Time. Further detail analysis is beneficial to obtained detailed results of implementation of recommended improvements. 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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