ADVANCED TRAFFIC CONTROL SYSTEM IMPACTS ON ENVIRONMENTAL QUALITY IN A LARGE CITY IN A DEVELOPING COUNTRY

A. Caroline SUTANDI
Senior Lecturer
Department of Civil Engineering
Parahyangan Catholic University
Ciumbuleuit 94 Bandung 40141
Indonesia.
Fax: +62 22 233692
Email: caroline@home.unpar.ac.id

Abstract: Advanced Traffic Control Systems (ATCS) have been used in large cities in developing countries to ease traffic congestion problems. Congestion causing poor traffic performance has negative impacts on economic productivity, environmental quality and safety. The aim of this paper is to evaluate the impact of ATCS on fuel consumptions and pollution emissions in a large city in a developing country with specific geometric and traffic behaviour. A large road network area in Bandung, Indonesia was used as a case study. Fuel consumptions and pollution emissions (CO, NOx, HC) data was obtained from combustion and emissions laboratory. The results found that the impact of ATCS on reducing fuel consumption and pollution emission is not good especially during peak periods that usually have more traffic congestion. In conclusion, the application of ATCS in the large city in a developing country is not effective to reduce traffic congestion and enhancing environmental quality.

Key Words: Advanced Traffic Control Systems, Environmental Quality, Developing Country.

1. 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 in developed countries. The average annual population growth in developing countries is estimated at around 5 per cent compared to 0.7 per cent in developed countries (Sinha, 2000). Furthermore, these cities face more severe transportation problems including low road network densities with narrow lane width, poor lane discipline, and high level of side friction in connection with on street parking and street vendor activities. Road authorities have now recognised that building additional road capacity alone does not help to solve traffic congestion. Advanced Traffic Control Systems (ATCS) have been used in these large cities to ease traffic congestion problems. Congestion causing poor traffic performance has negative impacts on economic productivity, environmental quality and safety, through higher fuel consumption, increased costs of goods and service, increased air pollution, and worsened safety conditions. However, it is unknown how the impact of ATCS in these large cities on environmental quality.

The aim of this paper is to evaluate the impact of ATCS on fuel consumptions and pollution emissions in a large city in a developing country with specific geometric and traffic behaviour. The evaluation of environmental impacts of ATCS relies heavily on the development of accurate and reliable environmental emission models. Microscopic traffic
simulation provides a number of advantages for this kind of study through detailed modelling of road geometry and the capability of modelling individual driver-vehicle-units to provide second-by-second fuel consumption and pollution emission on a section-by-section or network-wide basis. In this study, AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non Urban Networks) is used as a microscopic traffic simulator.

The data collection including geometric road network and traffic demand was carried on a large road network area in Bandung, Indonesia, where advanced traffic control systems SCATS (Sydney Coordinated Adaptive Traffic Control Systems) has been implemented in this city in June 1997 as a pilot project (AWA Plessey, 1996a, 1996b). Traffic demand data was recorded every 15 minutes from all 90 signalised intersections connected to SCATS in Bandung. Whereas fuel consumptions and pollution emissions (CO, NOx, HC) data as the input parameters into the simulator were the tests results of car engines commonly used in Bandung, in combustion and emissions laboratory. The car engine was conditioned according to particular velocity during idling, acceleration, deceleration, and cruising.

2. FUEL CONSUMPTION AND POLLUTION EMISSION MODELS

This section discusses fuel consumption and pollution emission models, input data requirements, and output generated by AIMSUN microscopic traffic simulator during idling, cruising at a constant speed, accelerating and decelerating, used in this study.

2.1 Fuel Consumption Model

During idling and decelerating vehicles, the rate (ml/s) can be assumed to be constant, and for accelerating vehicle it is given by formula (TSS, 2004a, TSS, 2004b):

\[ F_a = (c_1 + c_2 a v) \]  

(1)

where \( c_1 \) and \( c_2 \) are constants and \( a \) and \( v \) are the vehicle acceleration and speed respectively.

The following fuel consumption equation for a cruising vehicle moving at speed \( v \), has been determined by Akcelik (1982). It contains three constants: \( k_1 \), \( k_2 \), and \( v_m \) (speed at which the fuel consumed per km is a minimum), which need to be determined empirically for each vehicle type.

\[ \frac{dF}{dt} = k_1 (1 + \frac{v^3}{2v_m^3}) + k_2 v \]  

(2)

The UK Department of Transport (1994) provides fuel consumption figures for all new cars. Amongst the figures given is the fuel consumption in litres per 100 km, for vehicles travelling at speeds of 90 km/h and 120 km/h. These figures can be used to determine the constants \( k_1 \) and \( k_2 \) above. It is easy to show that if \( F_1 \) and \( F_2 \) are the fuel consumption rates in litres per 10 km/h for a vehicle travelling at a constant speed of either \( v_1 \) or \( v_2 \) respectively, then:

\[ k_1 = \frac{(F_1 - F_2) v_1 v_2 v_m^3}{180(2v_2 v_m^3 - 2v_1 v_m^3 - v_2 v_1^3 - v_1 v_2^3)} \]  

(3)
Then, for each step in the simulation, the state of each vehicle will be determined as either idling, accelerating, cruising, or decelerating. The fuel consumed during the simulation step, $\Delta t$, will then be calculated for each vehicle according to its state using the formula given in Table 1.

$$k_2 = \frac{2F_2v_2v_m^3 - 2F_1v_1v_m^3 + F_2v_2v_1^3 - F_1v_1v_2^3}{360(2v_2v_m^3 - 2v_1v_m^3 - v_2v_1^3 - v_1v_2^3)}$$  \hspace{1cm} (4)

Table 1 Fuel consumed (TSS, 2004b)

<table>
<thead>
<tr>
<th>Vehicle State</th>
<th>Fuel Consumption (ml) during $\Delta t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idling</td>
<td>$F_1\Delta t$</td>
</tr>
<tr>
<td>Accelerating with acceleration $a$</td>
<td>$(c_1+c_2av)\Delta t$</td>
</tr>
<tr>
<td>(m/s/s) and speed $v$ (m/s)</td>
<td></td>
</tr>
<tr>
<td>Cruising at speed $v$ (m/s)</td>
<td>$(k_1(1 + \frac{v}{v_m}^3) + k_2v)\Delta t$</td>
</tr>
<tr>
<td>Decelerating</td>
<td>$F_d\Delta t$</td>
</tr>
</tbody>
</table>

Where $F_i$ and $F_d$ are the fuel consumption rate in ml/s for idling and decelerating vehicle respectively and $c_1$ and $c_2$ are constants.

**Input Parameters**

The input parameters to the microscopic traffic simulator are for each vehicle type. The following parameters which specify the vehicle’s fuel consumption rates have to be specified:

- $F_i =$ the fuel consumption rate for idling vehicles in ml/s
- $c_1$ and $c_2 =$ the two constants in the equation for the consumption rate for accelerating vehicles, $F_a$, in ml/s
- $F_1 =$ the fuel consumption rate, in litres per 100 km, for vehicles travelling at a constant speed of 90 km/h
- $F_2 =$ the fuel consumption rate, in litres per 100 km, for vehicles travelling at a constant speed of 120 km/h
- $v_m =$ the speed at which the fuel consumption rate, in ml/s, is at a minimum for a vehicle cruising at constant speed
- $F_d =$ the fuel consumption rate for decelerating vehicles in ml/s

Output produced by the Fuel Consumption model (in litres) can be generated for the entire network, for each section and turning, or for each route by all vehicles having finished their trip, have crossed particular section, or have followed specific route, respectively.

**2.2 Pollution Emission Model**

As in fuel consumption model, the vehicle state (idling, cruising, accelerating, or decelerating) and the vehicle speed/acceleration is used to evaluate the emission from each vehicle for each simulation step in the simulator. Three most widely used pollutants (Carbon Monoxide, Nitrogen Oxides, and unburned Hydrocarbons) in g/s will be evaluated in this study.
Input Parameters
The input parameters required for the pollution emission for each vehicle type is as follows:

- Emission rate for accelerating vehicles in g/s
- Emission rate for decelerating vehicles in g/s
- Emission rate for idling vehicles in g/s
- A look-up table for vehicles cruising at a constant speed consisting of a set of pairs (speed break point (km/h), emission rate (g/s), for a maximum of 15 break points.

The output produce by the Pollution Emission model (g/s) is generated in the same conditions with those produce by the Fuel Consumption model.

3. DATA COLLECTION

A large road network area in Bandung, Indonesia was used as a study area. Four types of data were collected in this study including geometric detail data, traffic demand data, traffic control data, and fuel consumption and pollution emission data. SCATS 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.

The roads and intersections geometric 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, 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 throughput data of each loop detector at each intersection, plus queue length data from a number of critical intersections with CCTV; there were 4 to 14 loop detectors 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 (7:00 – 8:00 am), off peak (10:00 – 11:00 am) and afternoon peak (4:30 – 5:30 pm) periods. The data was used to validate the microscopic traffic simulation models and was not required as an input to develop the models.

The other field data required is traffic control data, including green time, amber time, all red time, cycle time, traffic directions, phases at each intersection, and possible turning movements for each lane.

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 throughput data
from each loop detector at each signalised intersection, in addition to queue length data from a number of signalised intersections with CCTV surveillance, the traffic control data and also travel time data, are believed to make up one of the largest sets of “real world” data available for the development, calibration, and validation of microscopic traffic simulation models.

The last data needed are fuel consumption and pollution emission data. The data as the required input parameters into the microscopic traffic simulator were the tests results of car engines commonly used in Bandung, in combustion and emission laboratory. The fuel consumption and pollution emission data are presented in Tables 2 to 4, and Figure 1 below.

Table 2 Fuel consumption laboratory test results

<table>
<thead>
<tr>
<th>Vehicle State</th>
<th>Fuel Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption rate for idling vehicles, $F_i$</td>
<td>0.2083 ml/s</td>
</tr>
<tr>
<td>Fuel consumption rate for vehicles travelling at a constant speed of 90 km/h, $F_1$</td>
<td>10.9 litres per 100 km</td>
</tr>
<tr>
<td>Fuel consumption rate for vehicles travelling at a constant speed of 120 km/h, $F_2$</td>
<td>11.3 litres per 100 km</td>
</tr>
<tr>
<td>Speed at which the fuel consumption rate is at a minimum for a vehicle cruising at constant speed, $v_m$</td>
<td>60 km/j</td>
</tr>
<tr>
<td>Minimum fuel consumption needed by vehicle cruising at constant speed $v_m$</td>
<td>7.35 litres per 100 km</td>
</tr>
<tr>
<td>fuel consumption rate for decelerating vehicles, $F_d$</td>
<td>0.2083 ml/s</td>
</tr>
</tbody>
</table>

Table 3 Fuel consumption rate for cruising vehicle at constant speed

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Fuel Consumption (lt/100 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>22.22</td>
</tr>
<tr>
<td>20</td>
<td>21.74</td>
</tr>
<tr>
<td>30</td>
<td>15.63</td>
</tr>
<tr>
<td>40</td>
<td>8.93</td>
</tr>
<tr>
<td>50</td>
<td>8.62</td>
</tr>
<tr>
<td>60</td>
<td>7.35</td>
</tr>
<tr>
<td>70</td>
<td>7.35</td>
</tr>
<tr>
<td>90</td>
<td>10.9</td>
</tr>
<tr>
<td>120</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Figure 1 Fuel consumption rates for various cruise speeds in litre per 100 km
Table 4 Pollution emission rates for car

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Pollution Emission (g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.013</td>
</tr>
<tr>
<td>NOx</td>
<td>0.011</td>
</tr>
<tr>
<td>HC</td>
<td>0.035</td>
</tr>
</tbody>
</table>

4. AIMSUN MICRO SIMULATOR

The evaluation of environmental impacts of ATCS implementation on fuel consumptions and pollution emissions in a large city in a developing country with specific geometric and traffic behaviour relies heavily on the development of accurate and reliable environmental emission models. Microscopic traffic simulator is used in this study to provide detailed modelling of road geometry and the capability of modelling individual driver-vehicle-units to provide second-by-second fuel consumption and pollution emission on a section-by-section or network–wide basis.

In this study, GETRAM (The Generic Environment for Traffic Analysis and Modelling) was used as a tool to evaluate the environmental impacts of ATCS implementation on fuel consumptions and pollution emissions in a large city in a developing country. 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 environmental impacts of ATCS on fuel consumptions and pollution emissions in a large city in a developing country.

5. ENVIRONMENTAL IMPACTS

Using the validated microscopic traffic simulation models, the environmental impacts of ATCS on fuel consumptions and pollution emissions in a large city in a developing country were evaluated at network-wide level, the road hierarchy level, and location of the road (in CBD or in residential area). Based on the same traffic demand and motorist behaviour, the distinguish traffic situation / traffic conditions as the impact of using SCATS and without SCATS can be explained through traffic performance measures differences that presented in Table 5 below. Table 5 shows that in general traffic performance measures under SCATS was not good as expected. More detail discussion regarding fuel consumption and pollution emissions are presented using Figures 2 to 9.
Table 5 Traffic performance differences between with and without SCATS in Bandung road network

<table>
<thead>
<tr>
<th></th>
<th>Flow (veh/h)</th>
<th>Queue Length (veh)</th>
<th>Density (veh/km)</th>
<th>Speed (km/h)</th>
<th>Travel Time (h:mm:ss)</th>
<th>Delay Time (h:mm:ss)</th>
<th>Stop Time (h:mm:ss)</th>
<th>Stop Time (no. stops/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCATS</td>
<td>53042</td>
<td>2075.9</td>
<td>2966.4</td>
<td>7968.8</td>
<td>14:10:48</td>
<td>8:13:23</td>
<td>7:35:26</td>
<td>460.9</td>
</tr>
<tr>
<td>FIXED</td>
<td>54585</td>
<td>1799</td>
<td>2689.2</td>
<td>8155.3</td>
<td>13:19:28</td>
<td>7:18:33</td>
<td>6:41:16</td>
<td>466.4</td>
</tr>
<tr>
<td>DIFF (%)</td>
<td>-2.83</td>
<td>15.39</td>
<td>10.31</td>
<td>-2.29</td>
<td>6.42</td>
<td>12.50</td>
<td>13.50</td>
<td>-1.18</td>
</tr>
</tbody>
</table>

Although both traffic control systems comparison are based on the same traffic demand and motorist behaviour, specific local conditions including poor lane discipline may influence the performance of ATCS since detectors can detect properly when the motorists are in the lane. The fuel consumption and pollution emissions as the results of comparative evaluation of the models with ATCS and without the application of ATCS (under fixed time traffic control system) are presented in Figures 2 to 9 below.

In large cities in Indonesia, include Bandung, the Fixed Time system at signalised intersections including the fixed cycle time and the fixed green time is based on the Indonesian Highway Capacity Manual (IHCM) – 1997, published by Directorate General of Highways, Directorate of Urban Road Development, Ministry of Public Works, Republic of Indonesia. In this manual, the methodology for analysing the signalised intersections is derived from the real geometric and traffic conditions in large cities in Indonesia (Indonesian Highway Capacity Manual, 1997).

![Figure 2: Fuel consumptions in Bandung road network](image1)

![Figure 3: Fuel consumptions in Bandung road network based location](image2)
Figure 2 shows that the impact of advanced traffic control systems SCATS on reducing fuel consumption in Bandung road network is not good. Fuel consumption under SCATS is higher than under fixed time traffic control system. This condition can happen because of geometric conditions and traffic behaviour of driver in Bandung. The low road network densities, only 3 percent of the whole city area, has to serve more than two million city resident with high population density and has also to serve more than 500,000 vehicles with high annual vehicle growth rate (6%) (AWA Plessey, 1996a, 1996b). Furthermore, poor lane discipline causes more traffic congestion. Vehicles in any lane at intersections, especially in direction with more than two lanes, may turn to the left, turn to the right, or straight through. Therefore, in these conditions advanced traffic control system cannot help to enhance traffic performance and reduce fuel consumption. In more detail, fuel consumption during peak periods especially during morning peak period is higher than during off peak period because activities and traffic congestion during morning peak period is the highest (Sutandi and Dia, 2005b).

In general, Figure 3 describes that fuel consumption in CBD is higher than in residential area. Furthermore, the impact of SCATS traffic control system in Bandung road network on reducing fuel consumption is better in residential area that has less traffic congestion than in CBD. This result confirms that SCATS cannot reduce fuel consumption in road network with limited road infrastructure and high traffic congestion with specific driver behaviour.

It can be seen in Figure 4 that based on road hierarchy, fuel consumption under SCATS is better in local roads than in arterial and collector roads that usually more congested. This result also confirms the previous result. In more detail, fuel consumption in collector roads is higher than in arterial roads. The condition can happen because collector roads distribute traffic between the arterial roads and the local street system (Ogden and Taylor, 1999). Therefore, collector roads have many cross roads with both arterial and local roads, wherein cross roads between different road hierarchy usually increase traffic congestion.

Figures 5 to 7 show that the impact of advanced traffic control system SCATS in Bandung road network on reducing pollution emission is not good, especially during morning peak and afternoon peak periods. Whereas during off peak period, the pollution emission of vehicles under SCATS traffic control system seems similar to under Fixed time traffic control system. This result consistent with the previous result that the impact of SCATS on enhancing environmental quality is worse during peak periods that usually has high traffic congestion.
Figure 5 Pollution emissions in Bandung road network with and without the application of SCATS during morning peak period

Figure 6 Pollution emissions in Bandung road network with and without the application of SCATS during off peak period

Figure 7 Pollution emissions in Bandung road network with and without the application of SCATS during afternoon peak period

In conclusion, it was found that the impact of advanced traffic control system on environmental quality is not good, especially during peak periods, because the application of this system in road network with limited road infrastructure, high population density, high number of vehicles, high traffic congestion, and poor lane discipline cannot help to increase environmental quality.
6. CONCLUSIONS

This study evaluated the impact of ATCS implementation on fuel consumptions and pollution emissions in a large city in a developing country with specific geometric and traffic behaviour. AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non Urban Networks) microscopic traffic simulator is used in this study to provide detailed modelling of road geometry and the capability of modelling individual driver-vehicle-units to provide second-by-second fuel consumption and pollution emission on a section-by-section or network–wide basis. The results presented in this paper clearly demonstrated that the impact of advanced traffic control system SCATS in Bandung road network on reducing fuel consumption and pollution emission is not good especially during peak periods that usually have more traffic congestion. Another result also indicated that the impact of this system on reducing fuel consumption is better in residential area and local roads that have less traffic congestion than in CBD and roads with higher road hierarchy. In conclusion, the application of this system in road network with limited road infrastructure, high population density, high number of vehicles, high traffic congestion, and poor lane discipline cannot help to increase environmental quality.

REFERENCES

Ott, R. Lyman, Longnecker, Michael (2001). An Introduction to Statistical Methods and Data Analysis, 5th edition, Duxbury 511 Forest Lodge Road Pacific Grove, CA 93950, USA.
