Comparative Analyses of Bus Lane Operations in Urban Roads Based On Simulation Models

シミュレーションモデルによる都市部のバス専用レーン運用に関する比較分析

Tran Vu Tu
Supervisor: Dr. Kazushi Sano

1. INTRODUCTION

Deploying public transport system in general as well as bus system in particular is an indispensable trend to relieve traffic congestion and improve traffic quality. However, improving the performance of public transport will usually cause unfavorable conditions for non-bus operations. Therefore, City planners have to decide proper policies to take shape of a harmonious and sustainable traffic system. According to HCM 2000, there are three types of bus lanes. Type 1 bus lanes have no use of adjacent lane; Type 2 bus lanes have partial use of the adjacent lane, which is shared with other traffic; and Type 3 bus lanes provide for exclusive use of two lanes by buses. It can be seen that, this classification was based on the degree of exclusivity of the bus lane. The greater the degree of exclusivity of the bus lane and the greater the number of lanes available for buses to maneuver, the greater the bus lane capacity. In Japan, besides the ordinary bus lane type and exclusive bus lane type, another type of bus lane – priority lane – has already been deployed for years. However, there have been very few researches about it. The special thing of this lane type is the complexity of non-buses in choosing lane and changing lane to avoid bus coming. This priority lane type concerns the degree of exclusivity of not only bus, but also other vehicles. This type can improve effectively the bus travel time and minimize negative impacts on non-bus as well. From three popular bus lane types in Japan, which are roadside exclusive bus lane, bus priority lane and ordinary lane, the scope of this paper just focuses on these bus lane types. For a main street with 2 lanes for each direction, the definitions can be expressed:

(1) Roadside exclusive bus lane case: The most left lane is used only for bus. The right lane is used mainly for non-buses (cars, trucks, small trucks) and partly for buses which want to overtake or turn right.
(2) Bus priority lane case: buses, cars, small trucks and big trucks can use both lanes to promote the trips. However, because the most left lane is the priority lane, non-buses (cars, small trucks and big trucks) will give up their ways to buses in the cases that there is a bus coming on the priority lane. It means other vehicles are allowed to use all lanes, provided that they do not obstruct the bus moving on the priority lane.
(3) Ordinary lane case: Buses and the other vehicles (non-buses) can use two lanes and freely change lanes if necessary.

From the three cases of bus lanes, it can be imagined that suffering from the low speed in the case of ordinary lane with mixed traffic flows, the travel time of buses is improved a lot when exclusive bus lanes are deployed. However, it is really a waste of space when the number of buses is usually much less than that of passenger cars in the case of exclusive lanes. Thus, non-bus travel time will be affected negatively in this case. To better the situation, a traffic system with priority bus lanes is introduced. The questions are how good the traffic performance in each bus lane type is and what threshold in deciding bus lane type for specific situation is. The research aims at answering the questions.

2. RESEARCH OBJECTIVES

The main objectives of this paper are as follows:

(1) The effectiveness of the three types of bus lane treatment, including exclusive bus lane, ordinary lane and especially bus priority lane in the improvement of traffic conditions.
(2) The importance and the sensitivity of main traffic volume, the average number of passengers on bus in choosing bus lane treatment.

3. METHODOLOGY

(1) Algorithm in Paramics programmer module

The distances between the buses and those vehicles are determined by the following formula:

$$d_{bus(i)-(j)} = \sqrt{(x_{bus(i)} - x_{(j)})^2 + (y_{bus(i)} - y_{(j)})^2}$$

where $(x_{bus(i)}; y_{bus(i)})$: Co-ordinates of bus i
$(x_{(j)}; y_{(j)})$: Co-ordinates of vehicle j moving in front of the above bus i, on lane 1.

The paper assumes that, through reflecting mirrors, the visibility of the driver on front vehicles to recognize any bus rearwards is in the range D from 20m to 60m. Therefore, vehicles within the distance of around 20m - 60m ahead from a bus will have following responses:

(a) If the vehicle and the bus travel on the bus priority lane (the vehicle now travels on lane 1), the vehicle will, if possible, move into lane 2, to give way for the bus coming.
(b) If the vehicle now travels on lane 2, the vehicle will not be allowed to move into lane 1 (prioritized lane for buses).

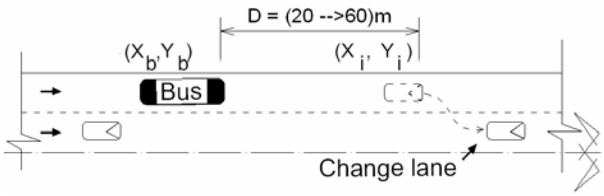

Figure 1 Lane changing vehicle

The above lane changes have two exceptions: one exception for the case that the vehicles want to turn left at intersections, and another for the case that the vehicles cannot change lanes concerning with having no acceptable gap for them to change lanes.

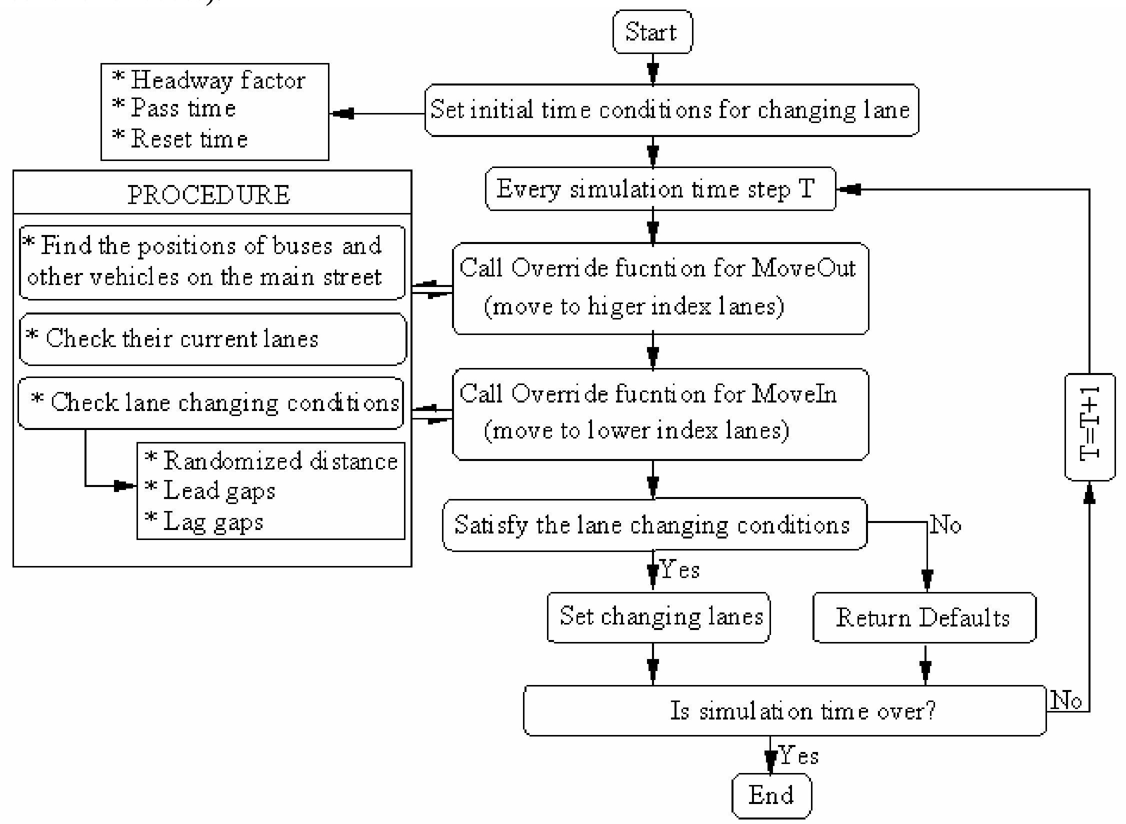

Figure 2 Algorithm used in Paramics for bus priority lane plugin

4. SIMULATION TESTS

(1) Traffic network and assumed data
The paper builds a hypothesis traffic network with the orientation of left hand driver. In this network, zone 1 and zone 2 are main zones, and other zones are on side streets. This study assumes that the side street demands are invariable while the main street demand is changeable. The side street traffic volumes are always 300vph in this research. The main street demand is divided into 7 levels corresponding to seven demand patterns. In each pattern, the simulation time is 5 hours from 6AM to 11AM. Each demand pattern has a warming up period (from 6AM to 7AM) with the traffic volume of 500vph, a transition period and a peak hour period with its traffic volume. The warming up period makes the simulation model more realistic and the peak hour periods are used to calculate vehicle travel times, which is considered at 7 levels: 500vph, 750vph, 1000vph, 1250vph, 1500vph, 2000vph, and 2500vph.

(2) Results from the simulation tests
The relationships between main the traffic volume and vehicle travel times are non-linear curves. Generally, the vehicle travel time increases when the main traffic volume increases.

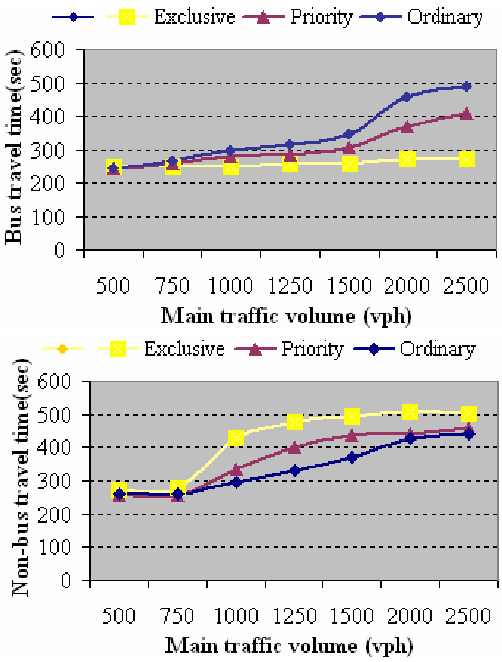

Figure 3 Travel times and main traffic volume

It is clear that the bus travel time is lowest in the exclusive case and highest in the ordinary lane case. Priority lane case can improve the bus travel time so much compared with the ordinary case. For non-bus travel time, it is straightforward to see that the travel time is lowest in the ordinary lane case and highest in the exclusive bus lane case.

5. A STUDY CASE

The study site is a main urban street near Nagaoka Station. The displays from the map and the interface of Paramics are as follows:

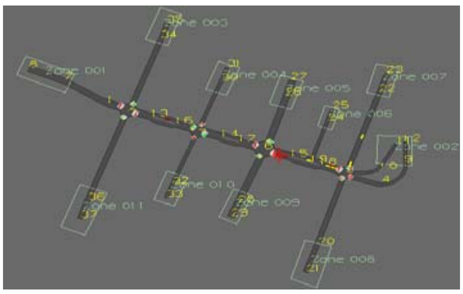

Figure 4 Traffic network in Paramics

(1) Model validation

From the simulated results and observation data, the traffic flows in 4 intervals during the peak hour from 8:00 to 9:00 are plotted around the 45-degree line, as shown in the figure 10. The values of simulated traffic flows and observed traffic flows distribute closely along the 45 degree line. The relative errors of traffic flows at all observed points are less than 15 percent

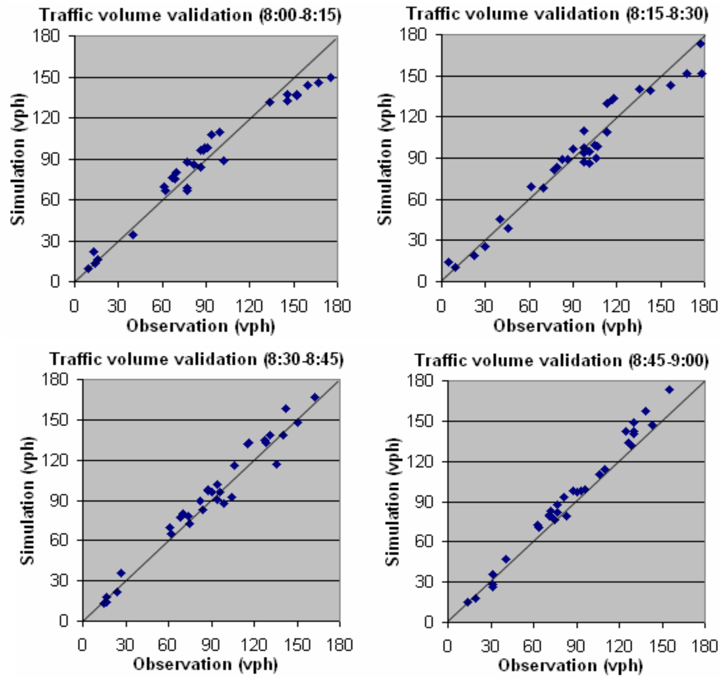

Figure 5 Traffic flow validation

The travel times of bus and other vehicles for each direction on the main street in the observation case and simulation case are approximately the same. The relative errors of travel times of bus and non-bus are less than 5 percent at each considered interval.

The comparisons of travel time for each period, for bus and non bus are as the following figures

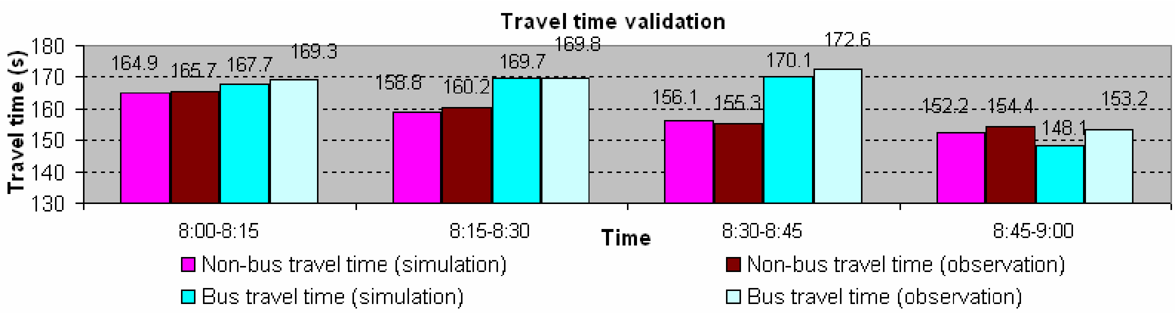

Figure 6 Travel time validation

(2) Comparative analysis

During the peak hour, there are 28 buses passing segment A1A2 on the studied direction. Based on the observation, the average number of passengers on each bus was 19.4 with the standard deviation of 3.2 for 28 buses and on each non-bus is 1.25 with the standard deviation of 0.4 for 110 passenger cars. Converting all bus travel time and non-bus travel time into passenger travel time, we can estimate the time needed for one passenger going from intersection 1 to intersection 4 with the results illustrated in the charts:

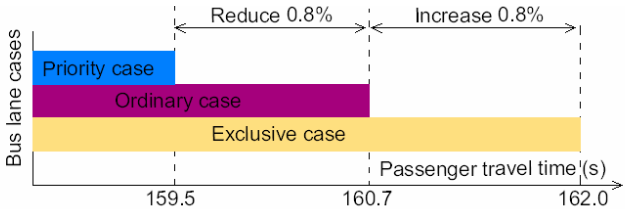

Figure 7 Passenger travel time comparisons

Compared with the exclusive bus lane and the ordinary lane case, the priority lane case has a very good performance in reducing passenger travel time. Indeed, for this direction, the priority treatment can reduce 1.2 (s) (or 0.8%) per passenger in comparison with the current ordinary lane case. Meanwhile, the exclusive bus lane treatment makes the passenger travel time increase by 1.3 (s) (equivalent to 0.8%). Although exclusive bus lane can improve bus travel time very much, its negative impacts on non-bus operation are significant in this case. Therefore, bus priority lane is a proper treatment, which can improve bus service and reduce negative impacts on non-bus simultaneously.

(3) Sensitivity analysis

The traffic volume and the number of passengers change every day, every hour. In addition, it is so difficult to count exactly the number of passengers on all buses and all passenger cars. Thus, the decision on choosing bus lane type would be changed according to the traffic situation. The research preserves the bus schedule in this study site and conducts an analysis of choosing bus lane treatment based on ranges of the number of passengers and main traffic volume. From the following figure, the violet Delta lines and blue Delta lines are contours of which values represent for the differences in passenger travel time between the case of ordinary and priority lanes. Similarly, the yellow Delta lines are also contours of which values represent for the differences in passenger travel time between the ordinary case and the exclusive lane case. There are two main points the research would like to bring out in this figure

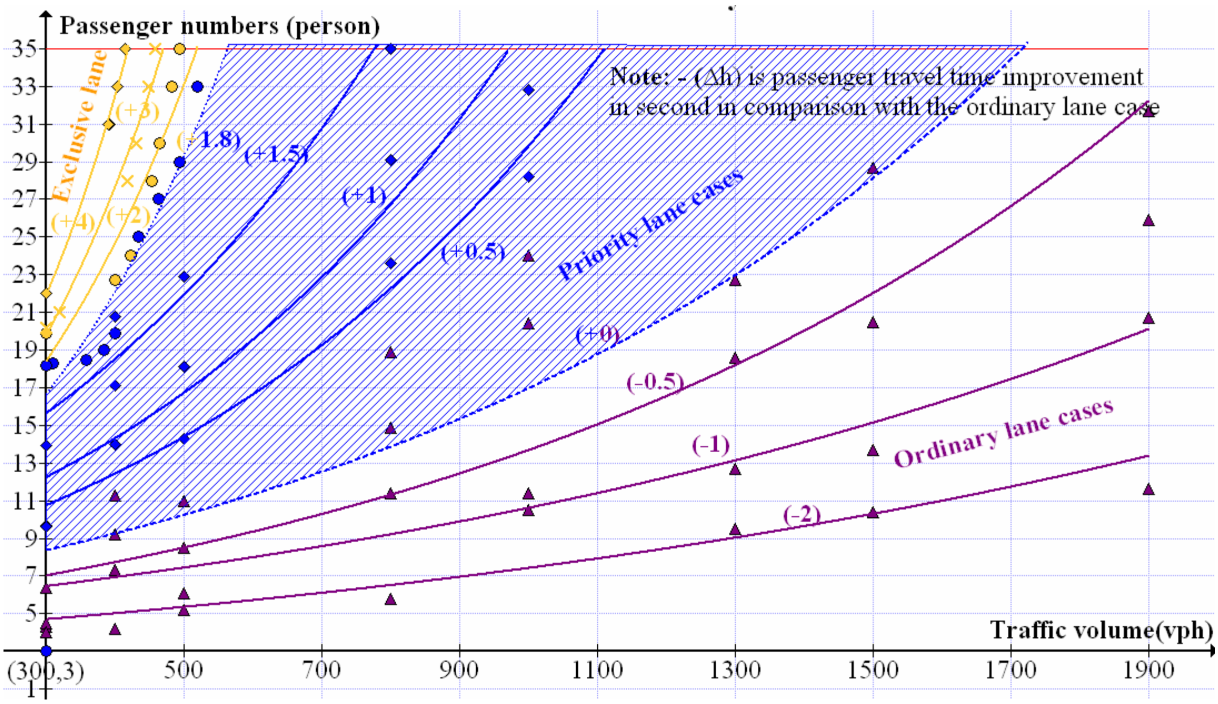

Figure 8 Decisions on bus lane types

The first one is the area distribution. It is easy to see that, the area with high number of passengers on bus and low main traffic volume is the most suitable for exclusive bus lane treatment (the area with yellow lines). Meanwhile the area with the low number of passengers on bus and high main traffic volume is good for ordinary lane case (the area with violet lines). The middle area with blue hatch, between the area for exclusive bus lane and the area for priority lane is proper for deploying priority lanes. If the priority lane were deployed in this area, the passenger travel time can be reduced by up to 1.8sec when traveling on a 500m main road segment. The second point the research wants to mention is the slopes of Delta lines. Both the main traffic volume and passenger numbers, in the scope of this research, are very important factors in choosing bus lane types. However, the slopes in the case of exclusive lane are very high compared with that in the other cases. It means that the dependence on passenger numbers in the exclusive lane case is very high, higher than that on the main traffic volume. These slopes decrease gradually from the case of exclusive bus lane to priority lane and finally to the ordinary lane case as shown in the figure when the main traffic volume increases. At that time, the dependence on the main traffic volume becomes more important than that on the passenger numbers.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

(1) The research comparatively analyzed the impacts of the three popular types of bus lane in Japan by using Paramics as a tool to simulate the bus lane types, especially for the case of bus priority lanes. The results showed that although the exclusive bus lane type can improve bus service so much, its negative impacts on general vehicles are significant. Thus if deployed at the study site, the exclusive bus lane would make the passenger travel time increase by 1.3sec on a 500m long urban street. Meanwhile, because of the flexibility in choosing lane in the priority lane case, developing bus priority lane at this study site can reduce 1.2sec for each passenger traveling the above urban street.

(2) In addition, the research conducted a sensitivity analysis in choosing bus lane types when the main traffic volume and the number of passengers on bus change. The analysis showed that the exclusive bus lane is proper for conditions in which the main traffic volume is low and the number of passengers on buses is high (the area with yellow lines). In this area, the passenger travel time improvement depends heavily on the passenger numbers. When the main traffic volume increases, the areas suitable for priority lane cases (the blue area) and ordinary lane case (the area with violet lines) are shown as the above figure. Then, the dependence on the number of passengers in improving passenger travel time gradually switches to that on the main traffic volume.

7.2 Recommendations

(1) The research would like to analyze the advantages of bus priority lane in the aspect of city planning for bus operations. Calibrations of parameters as well as further analyses of the model are beyond the scope of this research. That should be dealt with by further studies. In addition, a comprehensive investigation on factors influencing the decision of choosing bus lane types such as bus schedule, tuning flow rate, effective distance between intersections, the awareness of drivers, etc. should be considered and completed in future studies.

(2) Improving bus service and minimizing the negative impacts on other vehicles simultaneously are the essential targets in marking traffic policies. These targets can be obtained from the deployment of not only bus priority lanes, exclusive bus lanes but also bus signal priority system. Thus, focusing on studies about bus signal priority as well as combining the operations of bus priority lane and bus signal priority system is also a promising aspect for future works.

REFERENCES

1) Amer S.Shalaby (1999) Simulating performance impacts of bus lanes and supporting measures, **Journal of transportation engineering, Vol.125,** pp.390-397.
2) Cox, A.M. (1975). Reserved bus lanes in Dallas, Texas, **Journal of Transportation engineering, Vol. 101**, **No.4**, pp.691-705
3) Der-Horng Lee *et al* (2001) Customized Simulation Modeling Using PARAMICS Application Programmer Interface, **2001 IEEE Intelligent Transportation Systems**

Conference Proceedings-Oaskland (CA) USA, pp.842-847.

4) Gordon, Duncan, Paramics Technical Report, http://www.paramics-online.com/downloads/technicaldocs/Quadstone%20Paramics%20Car%20Follow.pdf
5) Highway Capacity Manual, TRB, National Research Council, Washington, D.C.,USA, 2000.
6) Huanyu, Y., Gan, A. and Ubaka, AICP. (2003), A decision model for bus – only and HOV lanes on freeways, **TRB Annual meeting CD-ROM.**
7) Hyung Jin KIM (2003), Performance of bus lanes in Seoul, **IATSS research, Vol.27, No.2**, pp.36-45.
8) Joy. D, *et al*, High occupancy vehicle lanes: not always more effective than general purpose lanes, **Transpn Res-A, Vol.32, No.2**, pp.99-114,1998
9) Kunihiro. S *et al*, Effectiveness of a bus-priority lane as a countermeasure for congestion, **TRB 2007 Annual Meeting CD-ROM**.
10) Lin Zhu *et al*, Simulation approach to the analysis of exclusive bus lane on Western 3rd ring-road expressway in Beijing, **TRB 2010 Annual Meeting CD-ROM**.
11) Minh. T *et al*, Modelling bus lane priorities in a motorcycle environment using SATURN, **TRB 2007 Annual Meeting CD-ROM**.
12) PARAMICS User Guide – Version 6.5 – Quadstone Limited, Edinburgh, UK, 2006
13) SEO, Young Uk *et al*.(2005), A study on setting-up a methodology and criterion of exclusive bus lane in urban area, **Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5,** pp.339-351.
14) Shalaby, S.A and Soberman, M.D. (1994), Effect of with flow bus lanes on bus travel times, **Transportation Research Record**, **No.1433**, pp.25-30.
15) Tanaboriboon, Y. and Toonim, S. (1983), Impact study of bus lanes in Bankok, **Journal of Transportation Engineering, Vol.109**, **No.2**, pp.247-255
16) Venkatachalam, T. A. and Perumal, V. (2008), Bus priority on Roads Carrying Heterogenous Traffic: a study using Computer simulation, **European Journal of Transport and infrastructure Research, Vol.8, No. 1**, pp.45-64.