ESTIMATION OF THE IMPACT OF AREA LICENSE SCHEME WITH MULTI-CLASS USER EQUILIBRIUM MODEL

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Abstracts: This study estimated the impact of the application of the Area License Scheme (ALS) using the Combined Modal Split and Traffic Assignment Multi-class User Equilibrium Model in the Bangkok Metropolitan Region (BMR) to reduce traffic congestion and consequently minimize air pollution. With varying toll cost under the scheme, mode shifting behavior, i.e. from passenger car to bus, as well as route choice were considered. The results showed that traffic congestion and air pollution can be reduced by introducing ALS. However, the influence of the scheme on income groups varied, with the lower income group making the mode shift while the higher income group continued using their cars even with increasing tollage.

Key Words: Area License Scheme, Multi-class User Equilibrium Model

1. INTRODUCTION

Large cities in Southeast Asia are facing serious traffic congestion and vehicle-related air pollution problems because of the increasing number of vehicular traffic. Since urban road infrastructure projects are limited due to budgetary constraints, it is of no doubt that Transportation Demand Management (TDM) measures could be the appropriate solution to alleviate these problems. Particularly, the Area License Scheme (ALS) method is one of the effective TDM measures that directly controls the use of cars in a congested area. This method has been carried out in some cities, like Singapore and Oslo, and showed significant improvement in alleviating traffic congestion and minimizing air pollution in these cities. For the Bangkok Metropolitan Region (BMR), the idea of introducing ALS has been proposed by several organizations such as the Thailand Government, the World Bank, and the Japan International Cooperation Agency (JICA), but this has not yet been realized.

In BMR, the rail transit which connects the suburbs to the CBD are still very limited, so buses are the only alternative mode of transportation. For some passenger car users, buses may not be suited to their standard of comfort and convenience. Hence, vehicular traffic may not be sufficiently reduced by ALS. One reason is that road users have large income differentials and if the TDM policy involves tollage like the ALS, its impact among income groups would vary. Utility may become much smaller for those on the lower end of the income scale than those on the higher end. This would likely cause unfairness, making it difficult to introduce the ALS. Given this issue, the study aimed to answer the following questions:

1) Is ALS really an effective policy to improve the traffic condition and the corresponding vehicle-related air pollution problem in a developing city like the BMR?
2) What kind of impact does ALS have on travel behavior among income groups?

The study developed a quantitative method to analyze the impact of ALS on the BMR. Specifically, the model called the Combined Modal Split and Traffic Assignment Multi-class User Equilibrium Model takes into account users' travel behavior and how they react to different levels of toll cost. Furthermore, the decision whether to shift modes or not depending on income levels of road users was also obtained. Two ALS cordon locations were considered, 1) in the inner ring road and 2) in the outer ring road of the BMR. The ALS effect on improving traffic conditions and the corresponding air pollution problems in terms of CO and NOx emissions were also measured.

The remainder of this paper is presented as follows; Chapter 2 is the review of existing studies that analyzed the effects of ALS; Chapter 3 summarizes the relationship between the users' travel behavior and their income levels; Chapter 4 gives in detail the development of the Combined Modal Split and Traffic Assignment Multi-class User Equilibrium Model with the users' attributes taken into consideration; Chapter 5 estimated the impact of the ALS among road users of two income groups and the corresponding effect on the traffic condition and air pollution levels; and Chapter 6 gives the conclusion.

2. EXISTING STUDIES

ALS is a measure which is a kind of road pricing. A large number of studies of road pricing have been made in the fields of transportation economics and transportation planning (e.g. Morrison, 1986; May, 1986), and it is said that the theoretical study has been nearly completed (Kato and Yamauchi, 2000).

On the other hand, ALS has actually been introduced in some cities such as Singapore and Oslo. Recently not only on the above-mentioned cities, but also London and Tokyo, have been considering to introduce it as one of the measures against urban traffic congestion and consequent air pollution. With these trends, some studies evaluated ALS targeted on actual cities (e.g. Richards *et al.*, 1996; Okuhira *et al.*, 2000; Matsumura *et al.*, 1999). These studies used the transportation demand estimation and the traffic simulation methods to estimate the influence of ALS on the traffic condition, social impact, and the improvement of the air environment in various ways of tollage and to investigate more effective applications of ALS.

In this study, the purpose is basically the same as the above-mentioned studies. However, in order to estimate the impact of ALS enforced in a large developing city with large income differentials, the analysis took into account the users' travel and route choice behavior according to travel cost. Specifically, the Combined Modal Split and Traffic Assignment Multi-class User Equilibrium Model in which the users were divided into the high income and low income groups, was developed to estimate the improvement of the traffic condition and the air pollution. The influence on users with different the income brackets in the case where ALS is introduced was also examined as well as the effectiveness of the policy.

3. THE RELATIONSHIP BETWEEN TRAVEL BEHAVIOR AND INCOMES IN BMR

Generally, in primate cities of developing countries like BMR, there is a wide range of income levels. For commuters, income level is strongly correlated to mode choice. Figure 1 shows the trip distribution by levels of income of the two commuter groups, namely, the bus and passenger car users. This figure was derived from the person trip survey conducted by the Office of the Commission for the Management of Land Transport (OCMLT) in 1997. Since the trips were segregated according to the two modes used by income levels[1], it can be seen that as income increases, more and more trips were made using the passenger car. The cut-off income bracket where more trips were made by passenger cars than those made by bus occurred at 11,000-14,999 Baht. Clearly, there are also car users in the lower income groups, and although account for a small percentage in the lower income levels, their percentage represent nearly half of the total passenger car users. Therefore, these passenger car users in the lower income groups may be greatly influenced by the introduction of ALS using tollage.

To validate the observations made, a questionnaire survey was conducted on commuters working in the central business district (CBD) in the inner ring road of BMR. Employees working at three government offices and seven private firms were chosen. There were 255 valid samples obtained, 87 of these were passenger car users and the remaining 113 were bus users. The survey was conducted for three days, from December 11 to 13, 2000.

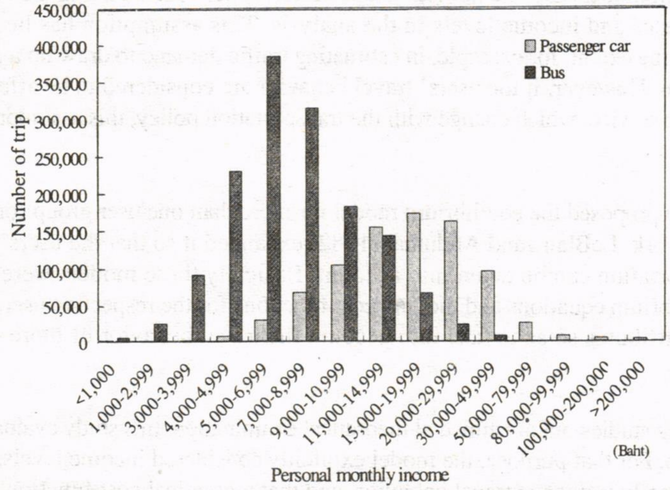

Figure 1. Trip Distribution by Level of Income of Commuter Groups

1 In this study, the monthly income of 15,000 Baht is set, the sum referred to as the average income level of university graduates in the BMR, as the dividing line between the high income group and the low income group (Tasaka, 1998).

Figure 2 shows the relationship between the cumulative probability of making a mode shift (i.e. from passenger car to bus) under changing levels of tollage by commuters with different levels of monthly income. The figure suggests that, as the cost of toll increases there is a decreasing probability of mode shift as income levels increases. At the highest tollage cost of 100 Baht, 100 percent mode shift is expected in the lowest income level while only around 62 percent is expected in the highest income level.

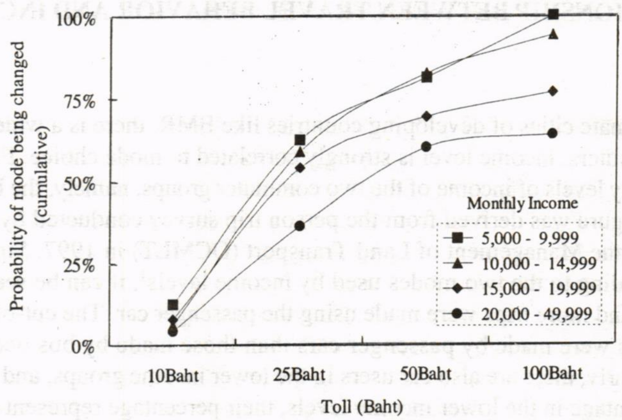

Figure 2. Cumulative Probability of Mode Shifting Under Increasing Tollage of Different Income Groups

4. COMBINED MODAL SPLIT AND TRIP ASSIGNMENT MULTI-CLASS USER EQUILIBRIUM MODEL

Many equilibrium models assume homogeneous users, namely users having the same attributes such as preferences and income levels in the analysis. This assumption has been considered permissible to some extent, for example, in estimating traffic demand to draw up a plan for future road construction. However, if the users' travel behavior are considered to be affected by travel cost and levels of service, which change with the transportation policy, this assumption would not be valid.

Dafermos (1972) proposed the equilibrium model for more than one user group (or vehicle type) on the road network. LeBlanc and Abdulaal (1982) expanded it so that the users' choice of the mode of transportation can be taken into account. Basically these models were expanded by setting the equilibrium equations and the link cost functions for the respective user groups which have different attributes so as to take into account the travel behavior of more than one user group.

While the existing studies mainly aimed at theoretical examination, this study evaluates the policy involving tollage. For that purpose, the model explicitly considered income levels, as one of the attributes that greatly influence travel behavior, and that a practical cost function is established and applied to an actual city.

4.1 Formulation

In this section, the Combined Modal Split and Traffic Assignment Multi-class User Equilibrium Model which takes into account the difference in the users' travel and route choice behavior according to travel cost and their mode shifting characteristics is developed. This study deems the value of time of users to depend on their income and fixes it for each income group. This made it possible to reveal the difference in travel behavior between income levels.

The relationship between link flow and path flow can be represented as follows ;

$$x^1_{a,j} = \sum_{r\in R}\sum_{s\in S}\sum_{k\in K^1_{rs}} f^{rs,1}_{k,j}\delta^{rs,1}_{a,k,j} \quad \forall a \in A, j \in J \tag{1}$$

Where,

$x^1_{a,j}$ is the flow on link a by group j of mode 1 (passenger car users) ;

$f^{rs,1}_{k,j}$ is the flow on path k from origin r to destination s by group j of mode 1 (passenger car users);

$\delta^{rs,1}_{a,k,j}$ is the indicator variable by mode 1 (passenger car) ;
(if link a is on path k between OD pair rs :1, otherwise :0) ;

A is the set of links a ;

R is the set of origin nodes r ;

S is the set of destination nodes s;

K is the set of path k from origin r to destination s by mode m of group j ; and

J is the set of user group j (j =1: high income group; j =2: low income group).

The relationship between route flow and OD trip volume on the road network is as follows ;

$$\sum_{k\in K^m_{rs}} f^{rs,m}_{k,j} = q^m_{rs,j} \quad \forall r \in R, s \in S, m \in M_{rs}, j \in J \tag{2}$$

Where,

$q^m_{rs,j}$ is the trip volume from origin r to destination s by mode m of group j ; and

M is the set of mode m (m =1: passenger car; m =2: bus) .

Assuming that each user chooses the minimum travel time route, the following equilibrium conditions are formulated. In this study, the general cost is used in order to evaluate the tollage policy.

$$f^{rs,m}_{k,j}\left(u^{rs,m}_{k,j} - u^m_{rs,j}\right) = 0 \quad \forall r \in R, s \in S, m \in M_{rs}, k \in K^m_{rs}, j \in J \tag{3a}$$

$$u^{rs,m}_{k,j} - u^m_{rs,j} > 0 \quad \forall r \in R, s \in S, m \in M_{rs}, k \in K^m_{rs}, j \in J \tag{3b}$$

$$f^{rs,m}_{k,j} > 0 \quad \forall r \in R, s \in S, m \in M_{rs}, k \in K^m_{rs}, j \in J \tag{3c}$$

Where,

$u^{rs,m}_{k,j}$ is the general cost from origin r to destination s by mode m of group j ; and

$u^m_{rs,j}$ is the minimum general cost from origin r to destination s by mode m of group j .

The general cost by passenger car and.bus users are represented as follows ;

$$u_{k,j}^{rs,1} = \sum_{a \in A} u_{a,j}^{1} \delta_{a,k,j}^{rs,c1} \quad \forall r \in R, s \in S, k \in K_{rs}^{1}, j \in J \tag{4a}$$

$$u_{a,j}^{1} = p_{a}^{1} + V_{j} t_{a}^{1} \quad \forall a \in A, j \in J \tag{4b}$$

$$u_{rs,j}^{2} = p_{rs}^{2} + V_{j} c_{rs}^{2} \quad \forall r \in R, s \in S, j \in J \tag{4c}$$

Where,

$u_{a,j}^{1}$ is the general cost by group j of mode 1 (passenger car users) on link a ;
p_{a}^{1} is the cost by mode 1 (passenger car users) on link a ;
(With ALS case: Tollage is included in the cost.)
V_{j} is the value of time by user group j ;
t_{a}^{1} is travel time by mode 1 (passenger car users) on link a ;
$u_{rs,j}^{2}$ is the general cost from origin r to destination s by group j of mode 2 (bus users);
p_{rs}^{2} is the cost from origin r to destination s by mode 2 (bus users) ; and
c_{rs}^{2} is the travel time from origin r to destination s by mode 2 (bus users).

The probability of user group j of choosing cars or buses is also offered by the Logit function as follows ;

$$q_{rs,j}^{1} = q_{rs,j}^{total} \frac{1}{1 + \exp \theta_{j} \left(u_{rs,j}^{1} - u_{rs,j}^{2} \right)} \quad \forall r \in R, s \in S, j \in J \tag{5a}$$

$$q_{rs,j}^{2} = q_{rs,j}^{total} - q_{rs,j}^{1} \quad \forall r \in R, s \in S, j \in J \tag{5b}$$

Where,

$q_{rs,j}^{total}$ is the total trip volume from origin r to destination s of group j ; and
θ_{j} is parameter.

The relationship between traffic volume on a link and travel time is represented by the BPR function.

$$t_{a}^{1} = t_{a0} \left[1 + \alpha \left\{ (x_{a,j=1}^{1} + x_{a,j=2}^{1}) / c_{a} \right\}^{\beta} \right] \quad \forall a \in A \tag{6}$$

Where,

t_{ao} is the free flow travel time on link a ;
c_{a} is capacity on link a ; and
α , β are parameters.

This Combined Multi-class User Equilibrium Model formulated in eq.(1)~eq.(6) takes the form of a user equilibrium model with link interactions. In this model, the equivalent optimum problem was not established because the general cost functions are asymmetrical.

4.2 Solution Algorithm

The model formulated in section 4.1 takes the form of an equilibrium model with interactions between links (i.e. the income levels in this study). For the solution of such a problem, the following algorithm is being proposed. This study uses the diagonalization algorithm, which has been applied to relatively many cases. It is an algorithm in which the diagonalization problem, obtained by fixing the interactive part of the link cost function, is repeatedly solved in the iteration. To put it concretely, in the calculation of the travel time of the high income group for example, by regarding the traffic volume of the other group, namely the low income group, as a constant, it ends in iteratively solving the equilibrium problem without link interactions. Besides, in making the calculations more efficient, one inputs the number of iteration for solving the diagonalization problem. This method was proposed by Sheffi(1985) and is similar to the Frank-Wolfe algorithm.

Step 0 : Initialization.

Iteration number $n=1$. Find an initial feasible solution $\mathbf{x}_j^{1,n-1}$, $\mathbf{q}_j^{1,n-1}$, $\mathbf{q}_j^{2,n-1}$.

Step 1 : Update of travel time.

$$t_a^{1,n} = t_a(\mathbf{x}_{j-1}^{1,n}, \mathbf{x}_{j-2}^{1,n}) \qquad \forall a \in A$$

Step 2 : Direction finding.

(a) Compute $\mathbf{u}_j^{1,n}$ by searching the minimum cost route based on $\mathbf{t}^{1,n}$.
(b) Compute OD trip volume by Logit function based on $\mathbf{u}_j^{1,n}$.

$$v_{rs,j}^1 = q_{rs,j}^{total} \frac{1}{1+\exp\,\theta_j\left(u_{rs,j}^1 - u_{rs,j}^2\right)} \qquad \forall r \in R, s \in S, j \in J$$

(c) Assign $\mathbf{v}_j^{1,n}$ to the minimum paths identified (a). This yields auxiliary link flow $\mathbf{y}_j^{1,n}$.

Step 3 : Move-size determination.
Find α that solves the following problem.

$$\min.\ Z\left[\mathbf{x}_j^{1,n} + \alpha\left(\mathbf{y}_j^{1,n} - \mathbf{x}_j^{1,n}\right), \mathbf{q}_j^{1,n} + \alpha\left(\mathbf{v}_j^{1,n} - \mathbf{q}_j^{1,n}\right), \mathbf{q}_j^{2,n} + \alpha\left(\mathbf{v}_j^{2,n} - \mathbf{q}_j^{2,n}\right)\right]$$

$$subject\ to \quad 0 \le \alpha \le 1$$

Where Z is following function.

$$Z = \frac{1}{2}\left\{\sum_{a\in A}\int_0^{x_{a,j-1}^1} u_{a,j}^1(\omega, x_{a,j-2}^1)d\omega + \sum_{a\in A}\int_0^{x_{a,j-1}^1} u_{a,j}^1(\omega,0)d\omega\right\} + \frac{1}{2}\left\{\sum_{a\in A}\int_0^{x_{a,j-2}^1} u_{a,j}^1(x_{a,j-1}^1,\omega)d\omega + \sum_{a\in A}\int_0^{x_{a,j-2}^1} u_{a,j}^1(0,\omega)d\omega\right\}$$

$$+\sum_j\sum_{rs} u_{rs,j}^2 q_{rs,j}^2 + \sum_j\sum_{rs}\frac{1}{\theta_j}(q_{rs,j}^1 \ln q_{rs,j}^1 + q_{rs,j}^2 \ln q_{rs,j}^2)$$

Step 4 : Revise.

$$\mathbf{x}_j^{1,n+1} = \mathbf{x}_j^{1,n} + \alpha\left(\mathbf{y}_j^{1,n} - \mathbf{x}_j^{1,n}\right)$$

$$\mathbf{q}_j^{1,n+1} = \mathbf{q}_j^{1,n} + \alpha\left(\mathbf{v}_j^{1,n} - \mathbf{q}_j^{1,n}\right)$$

$$\mathbf{q}_j^{2,n+1} = \mathbf{q}_j^{2,n} + \alpha\left(\mathbf{v}_j^{2,n} - \mathbf{q}_j^{2,n}\right)$$

Step 5 : Convergence test.

If $\left\|\mathbf{x}_j^{n+1} - \mathbf{x}_j^{n}\right\| \leq \varepsilon$ stop ; Otherwise, set $n = n+1$, and go to *Step 1*.

4.3 Application to BMR

This section includes the application of the developed model to the case of the BMR in order to test its reproducibility.

4.3.1 Conditions

(1) Road Network
The network in BMR is shown in Figure 3. It consists of 2,122 links and 1,583 nodes. The study area consists of 57 zones.

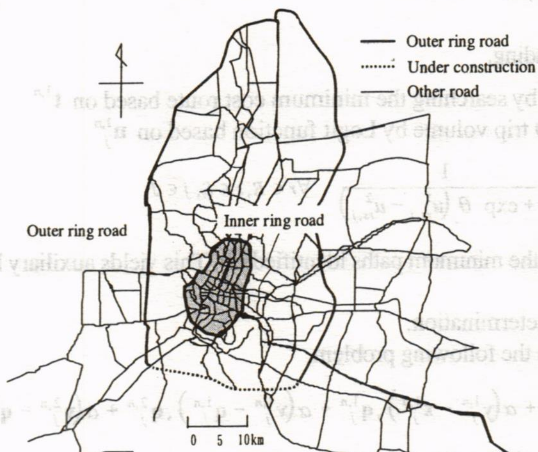

Figure 3. Study Network of BMR

(2) OD Traffic Volume
For the OD traffic volume during the period of commuter time, the trips departing between 6:00 a.m. and 9:00 a.m. are selected from among the commuter trips by passenger car or bus users as derived from the person trip survey conducted by the OCMLT.

(3) Levels of Service
As to the travel time on the link, the BPR link cost function is used for passenger cars, so that an increase in the travel time due to congestion is taken into consideration. As for buses, since they run on ordinary roads and are influenced by road traffic, the travel time is fixed at twice as much as that of passenger cars, including the time for passengers to get on and off the bus.

(4) Travel Cost
For the travel cost of passenger cars, the values of travel speed are applied on the basis of existing reports (JICA, 1990). For the travel cost of buses, since the person trip survey has revealed that many users use the Red Bus or the Blue Bus, the cost is fixed across the board at 3.5 Baht, which is equivalent to their fare.

(5) Value of Time
This study deems the value of time for the users to depend on their income and fixes it for each income group. This makes it possible to reveal the difference in travel behavior between the income levels. The users are divided into two groups according to their monthly income: the high income group earning is equal to or more than 15,000 Baht, the sum referred to as the average income level of university graduates in the BMR today, while the low income group earning less than that level. The OD traffic volume is also divided based on the proportion of the income groups. The time value is fixed at 160 Baht/h for the high income group and 40 Baht/h for the low income group in light of the estimates by existing reports (JICA, 1990) and income distribution.

(6) Parameters
In the BPR link cost function, shown in formula 4.1, the travel speed derived from the road network data is used for the free speed. Parameter α and β are fixed at 0.96 and 1.2 respectively from a previous study (Mizokami et al. 1989), though it is fundamentally necessary to determine them in light of the actual traffic condition. Also, as to the parameters of the Logit function shown in eq.(4a), θ_1 is fixed at 0.005 and θ_2 at 0.1.

4.3.2 Estimation of Traffic Volume

Based on the conditions detailed in section 4.3.1, the established model was tested as to whether it can reproduce the link flow of passenger cars by estimation. The criterion of convergence (ε=0.1) was satisfied after 32 times of iteration (CPU time is 8 min: Pentium 750MHz). The data for verification are derived from the traffic counts (76 sections) in the traffic count survey conducted by OCMLT. As the indicators to evaluate goodness of fit, the partial regression coefficient a of regression function $y = ax$ and %RMSE were used.

Table 1 shows the calculations of these indicators, and Figure 4 the correlation between the observed values and the estimated values. As indicated by the value of partial regression coefficient a and in the correlation figure, the estimates were a little scattered. That is because the OD traffic volume used for the estimation was the trips starting between 6:00 a.m. and 9:00 a.m., so there were a certain number of passenger cars traveling along the observation section after 9: 00 a.m.

Table 1. Verification of the Estimated Link Flow Parameter

Coefficient a	0.67
%RMSE	81%

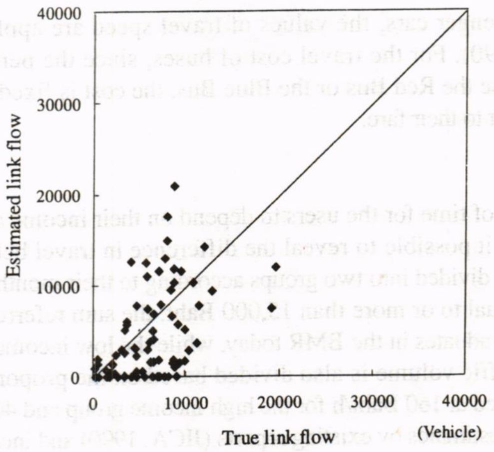

Figure 4. Verification of the Estimated Link Flow Parameter

5. ESTIMATION OF IMPACT OF AREA LICENSE SCHEME IN BMR

Several organizations, including the Government of Thailand, the World Bank and the Japan International Cooperation Agency (JICA), have proposed to apply ALS in BMR. Basically, the concept is to restrict entry into the area surrounded by the inner ring road (please see Figure 3). This study also examined the application of the cordon line on the outer ring road. The ALS tollage was set in 3 levels, specifically, 10, 30, and 50 Baht, for sensitivity analysis.

5.1 Impact on The Road Network

In order to analyze as to what extent the traffic volume and level of service on the road network would change after the introduction of ALS, the OD traffic volume of each mode and the average travel speed on the road network with and without ALS were estimated. The proportion of mode shifting was also examined under increasing toll cost.

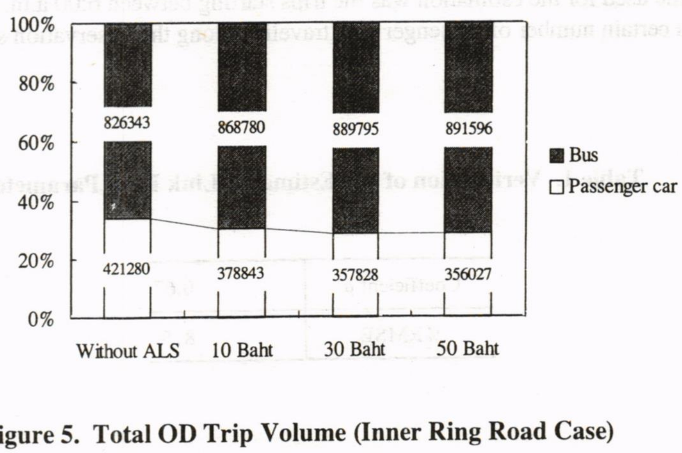

Figure 5. Total OD Trip Volume (Inner Ring Road Case)

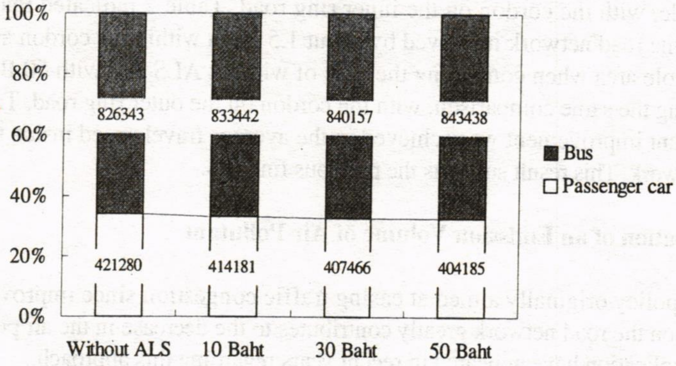

Figure 6. Total OD Trip Volume (Outer Ring Road Case)

Table 2. The Travel Speed (Inner Ring Road Case)

Average speed(km/h)		Inside of cordon	Whole network
Without ALS		17.0	20.7
Tollage	10 Baht	17.8	21.1
	30 Baht	18.4	21.3
	50 Baht	18.5	21.5

Table 3. The Travel Speed (Outer Ring Road Case)

Average speed(km/h)		Inside of cordon	Whole network
Without ALS		19.8	20.7
Tollage	10 Baht	19.9	20.9
	30 Baht	19.7	20.4
	50 Baht	19.9	20.6

Figures 5 and 6 show the change in the OD traffic volume of the two modes with increasing toll cost in the inner ring and outer ring roads as cordons, respectively. Tables 2 and 3 correspond to the change in the average travel speed in these two cases.

As seen in both Figures 5 and 6 there is a small decline in the proportion of OD traffic volume of passenger cars with increasing tollage. Moreover, the decrease in the inner ring road was more pronounced than in the outer ring road. One possible reason for this is that a greater number of passenger car users shifted to buses when entering the inner cordon line. Also, since most origins and distribution of commuters are inside the outer ring road, little is gained when the ALS is applied in the outer ring road. The figures also suggest that, as the toll cost increases, there is only a gradual reduction in the proportion of OD traffic volume of passenger cars. This suggests that when the toll cost exceeds a certain level, limited gain in mode shifting can be achieved using ALS.

Meanwhile, with the cordon on the inner ring road, Table 2 indicated that the average travel speed on the road network improved by about 1.5 km/h within the cordon area and by 0.8 km/h on the whole area when comparing the case of without ALS and with 50 Baht as tollage in the ALS. Using the same comparison, with the cordon on the outer ring road, Table 3 indicated that insignificant improvement was achieved in the average travel speed inside the cordon or on the whole network. This result supports the previous findings.

5.2 Estimation of an Emission Volume of Air Pollutant

ALS is a policy originally aimed at easing traffic congestion since improvement in the traffic condition on the road network greatly contributes to the decrease in the air pollution. Some cases of ALS application have appeared in recent years regarding this approach.

In this section, with the estimated traffic volume and travel speed along links known, the improvement in the air pollution using ALS can be projected. The average NOx and CO emission factors shown in Table 4 (JICA 1997) are the variables obtained for BMR. The intermediate values of these data were obtained using the complementary method.

Table 4. Emissions Factors

Pollutants	Vehicle Type	Average Speed (km/h)				
		0-1	8	16	24	32
NOx (g/km)	Small	5.23	2.06	1.87	1.85	1.93
CO (g/km)	Small	491.43	156.74	75.92	50.66	40.80

Note :
Small ; Passenger Car, Samlor, Taxi, Station Wagon
Source : Air Emission Database of Vehicles and Industry in Bangkok Metropolitan Region 1992 : PCD MOSTE

Figures 7 and 8 show changes in the emission volume of air pollutants in the inner ring and outer ring roads, respectively. In both cases, the NOx and CO emissions decreased with the application of ALS. Comparing the two cases, the decrease in emission was larger in the inner ring road case. As mentioned earlier, the probable reason is due to the decrease in the OD traffic volume of passenger cars and the correspoding improvement in travel speed was greater in the inner ring road case than in the outer ring road case. However, as the toll cost went up, the effectiveness of removing pollutants diminished since insignificant proportion of those using passenger cars shifted to buses was achieved.

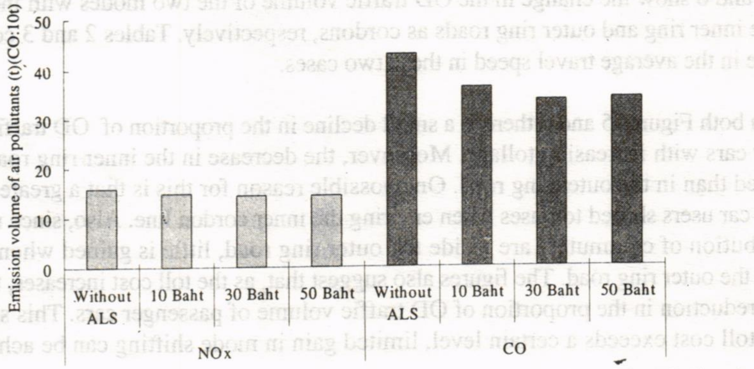

Figure 7. Emission Volume of Air Pollutants (Inner Ring Road Case)

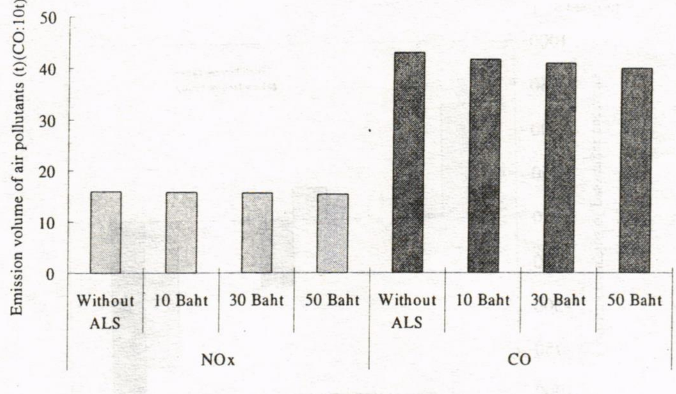

Figure 8. Emission Volume of Air Pollutants (Outer Ring Road Case)

5.3 Impact on Individual Income Groups

Figure 9 shows the changes in the OD traffic volume by mode of transportation previously shown in section 5.2, but this time divided according to income groups. It revealed that most commuters who converted from passenger cars to buses belonged to the low income group. Most of the passenger car users in the high income group remained with their mode of travel.

In Figure 10, the consumer surplus of passenger car users became much lower in the low income group than in the high income group because the low income group has a very small user benefit to start with. Therefore, it was judged that a further toll increase would hardly produce mode changing in the high income group and even would lead to an additional financial burden and reduced mobility for the low income group. These results suggest that the enforcement of ALS in an area where commuters have large income differentials give different influences on income groups and consequently could cause a large impact on society in terms of changes in travel behavior.

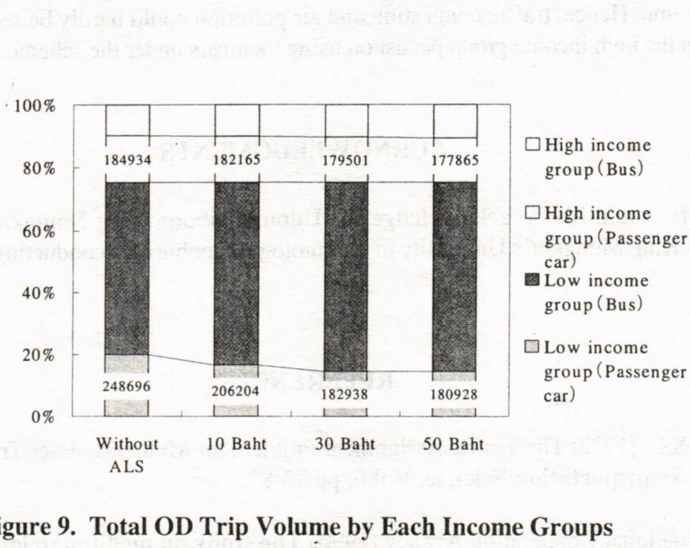

Figure 9. Total OD Trip Volume by Each Income Groups (Inner Ring Road Case)

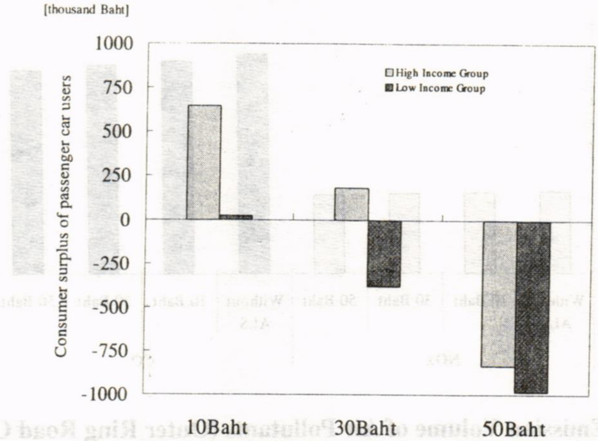

Figure 10. Consumer Surplus by Each Income Groups (Inner Ring Road Case)

6. CONCLUSION

The application of the Area License Scheme (ALS) with tollage in a developing city like the Bangkok Metropolitan Region (BMR) where road users have large income differentials was studied. The study estimated the impact of the ALS using the Combined Modal Split and Traffic assignment Multi-class User Equilibrium Model which took into account users' mode and route choice and how they react depending on their income, whether to shift mode or not, under increasing toll cost. The impact of ALS on the two income groups varied. The road users who shifted modes from passenger cars to buses belonged to the low income group while passenger car users in the high income group continued using their cars even with increasing toll cost.

The result showed that traffic congestion can be minimized and air pollution reduced by introducing ALS. However, it is the passenger car users in the low income group that are greatly affected by this scheme. Hence, traffic congestion and air pollution could hardly be reduced if passenger car users in the high income group persist on using their cars under the scheme.

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