The Evaluation of Road Pricing for the Tokyo Metropolitan Area with Respect to the Environment

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Abstract: The Tokyo metropolitan area is currently suffering from massive traffic jams that promote Nitrogen Oxide (NOx) air pollution. Hence the Tokyo metropolitan government is considering the enforcement of 'road pricing' as one of the policies of Transportation Demand Management (TDM). Four kinds of pricing-boundary schemes proposed by the Tokyo metropolitan government are considered. It is expected that air pollution would partly deteriorate just beyond the pricing boundary due to detouring traffic but that would gradually improve. It's necessary to consider such environmental deterioration when enforcing road pricing albeit the research is not complete. Hence the purpose of this study is to quantitatively evaluate such environmental deterioration. The present traffic condition was represented by the traffic simulator VISUM/DYNEMO that includes the fluid traffic-flow model which is effective for reproducing the heavy traffic flow in macro scale network such as the Tokyo Metropolitan Area. The traffic-simulation model was then verified by comparing the simulated and observed traffic volumes. Finally, we evaluate the total improvement and the partial deterioration due to road pricing. This study determined which pricing-boundary scheme is the best with respect to the impact of detouring vehicles.

Keywords: *traffic simulator; road pricing; nitrogen oxide; Tokyo metropolitan*

1. INTRODUCTION

The Tokyo metropolitan area is currently suffering from massive traffic congestion that promote Nitrogen Oxide (NOx) air pollution. Nitrogen oxides (NOx) emitted from vehicles become oxidants and is the cause of acid rain. Tokyo road pricing that the Tokyo Metropolitan Government (TMG) is now discussing, is an effective remedy for this situation. There are four kinds of pricing-boundary schemes proposed by TMG that are being considered. However, its quantitative evaluation is not sufficient. So the purpose of this study is to quantitatively evaluate the change of NOx emission with respect to each pricing-boundary scheme, using the traffic simulator VISUM/DYNEMO.

Matsumura et al (2001) evaluated improvement of air pollution due to road pricing within the Osaka central area. Okuhira et al (2000) carried out a similar research for the Tokyo metropolitan area. They used static assignment in order to estimate the traffic volume for each road network. The static assignment does not consider any vehicle movement. It just distributes vehicles about the traffic road network based on certain criteria and an origin-destination matrix. On the other hand, the traffic simulator DYNEMO is a dynamic-traffic simulator that represents vehicles movements. In this study, we use DYNEMO to represent traffic flow more accurately.

2. METHOD

2.1. Study Area and road pricing scheme

The study area is the central metropolitan area of Tokyo including Chiba, Saitama, and Kanagawa prefectures. The dimension is 70km (east/west) by 55km (north/south) as shown in Figure 1. The total population of Tokyo, Chiba, Saitama, and Kanagawa area is more than 33 million with 15 million registered vehicles.

Figure 1. Study area

TMG proposed four different pricing areas as shown in Figure 2. The pricing areas vary from 16 to 233 km^2 for the center of metropolitan Tokyo. Target vehicles are all vehicles that enter the pricing boundary except public transportation and emergency vehicles. Pricing is effective between 7:00 a.m. and 7:00 p.m. on weekdays. Proposed tolls are 400-600 yen for small vehicles and 800-1200 yen for heavy-goods vehicles (HGV), respectively.

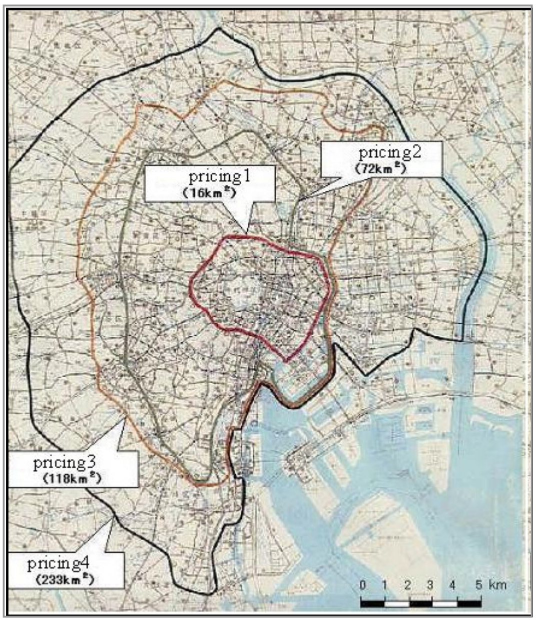

Figure 2. Pricing-boundary of Tokyo road pricing.

2.2. Traffic Simulator

A DYNEMO traffic simulator developed and distributed by Planung Transport Verkehr AG in Germany is used to reproduce traffic flow pattern. The DYNEMO is a traffic-flow model rather than a static-assignment model that distributes vehicles per link based on the origin/destination matrix. A link is a minimum unit (segment) of a road. DYNEMO is a kind of fluid model and simplifies vehicle movement. The vehicles are grouped in packets in order to simulate traffic flow. DYNEMO enable dynamic route choice based on the link condition during the simulation. DYNEMO is suitable to simulate heavy-traffic flow especially for large-scale networks like the Tokyo metropolitan area because of the simplified representation of traffic flow.

In DYNEMO, link is divided into about 200m sections with assumed uniform traffic conditions. Then a vehicle's speed is estimated based on the traffic density per time step. The vehicle's route is determined by a cost function that consists of route length, travel time, and user-defined factors. The user can determine the weight of each cost-function factor. Because the travel-time factor is dependent on the traffic condition, DYNEMO recalculate the travel-time factor and hence re-select a route based on information of new traffic condition per time interval. Using this function, it's possible to distinguish the normal from the special vehicles that are equipped with navigation systems that gives dynamic route-guidance.

2.3. Road network and traffic simulation

A road network consists of nodes and links. Link is a segment of road, and a node is at both end of a link. The road network in DYNEMO consists of 3887 nodes and 5047 links (10094 both direction) as shown in Figure 3. In our study, we use travel time to define the cost function for all vehicles and we set the time step for 10 seconds. We did not utilize dynamic route guidance in our simulation. The output from traffic simulation such as traffic volume, average link speed, and so on, is collected per hourly basis.

Figure 3. Road network in DYNEMO.

First, present traffic flow pattern within the Tokyo metropolitan area during a weekday was reproduced by traffic simulation using DYNEMO. The snapshot of DYNEMO's traffic simulation is shown in Figure 4. The results are compared with observed traffic pattern to verify our traffic model.

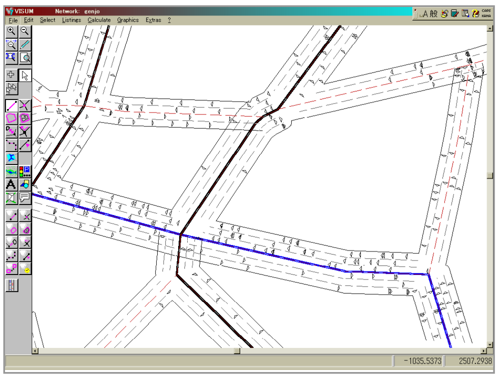

Figure 4. Snapshot of DYNEMO's traffic simulation.

After verifying our model, each road pricing is applied to traffic simulation by modifying the original origin/destination matrix. The factor of this modification is based on TMG's survey. TMG surveyed how drivers react against the proposed road pricing plans as shown in Table 1. About half of the private-vehicle users will change their behavior patterns. On the other hand, only 30% of heavy-goods vehicle (HGV) users were affected. The reason of this difference might be that most of HGV users are commercial users so they can add road-pricing fees to their cost.

Table 1: Reaction against road pricing

	small car	HGV
quit using car	**34%**	**10%**
change departure time	**7%**	**5%**
detour around pricing area	**8%**	**16%**

2.4. Emission model

Each road-pricing scheme was evaluated for its environment impact using the Nitrogen Oxide (NOx) emission as the index. The emission from each vehicle type was calculated per speed which was adopted from the Tokyo Metropolitan Government model (Figure 5). The traffic emissions were aggregated on an hourly basis.

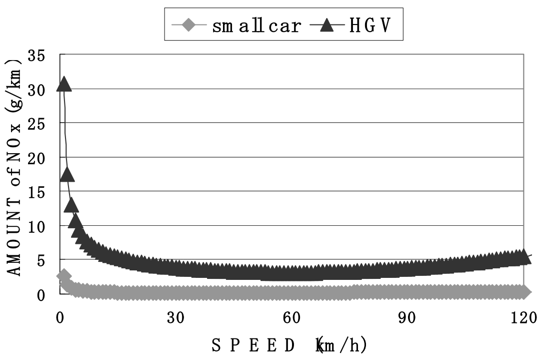

Figure 5. Emission table for NOx (Tokyo Metropolitan Government, 2000).

3. RESULTS AND DISCUSSION

3.1. Verification of our traffic model.

Simulated daily total traffic volume is compared with observed traffic volume at 72 evaluation points in Figure 6. The linear regression is also shown in Figure 6. The simulated traffic volume is greater than the observed one. This is due to limitation of our road networks in DYNEMO that neglect the minor road network.

The hourly traffic volume is compared in Figure 7. The correlation coefficient between simulated and observed traffic volumes is 0.78. Based on our verification study, we consider our traffic model is validated and we use it evaluation of road pricing.

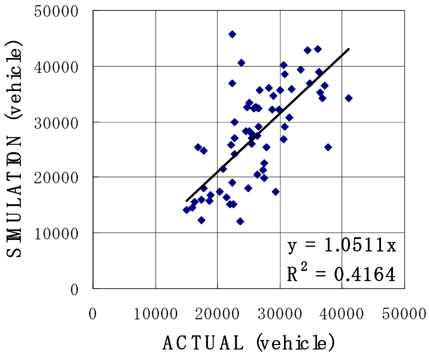

Figure 6. The comparison of daily total traffic volume.

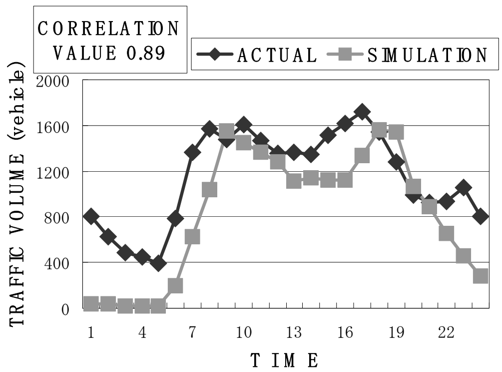

Figure 7. The diurnal variation of traffic volume at Tomigaya in Ring-road 6.

3.2. Total reduction of NOx emission

The total reduction of NOx emission by each road pricing is shown in Table 2. It is clear that the amount of NOx reduction depends on the road-pricing area when comparing the total improvement of the network. The larger the pricing area, the larger the reduction rate. The maximum reduction rate of 5.32% is expected by road pricing scheme 4. Based on the total reduction of NOx emission, road pricing 4 should be the better pricing scheme.

Table 2. The rate of decrease of amount of NOx emission over the network

	pricing1	pricing2	pricing3	pricing4
RATE of DECREASE (%)	1.26	2.91	3.69	5.32

3.3. Hourly reduction of NOx emission

Road pricing is applied to road networks between 7:00 a.m. and 7:00 p.m. Therefore, it is easily expected that more vehicles cross the pricing boundary before 7:00 AM and after 7:00 PM. The hourly reductions of NOx emission were aggregated in order to confirm this effects as shown in Figure 8 and 9. The negative reductions indicate NOx emission increase due to the road pricing for all of four different road pricing scheme before 7 AM and after 7 PM.

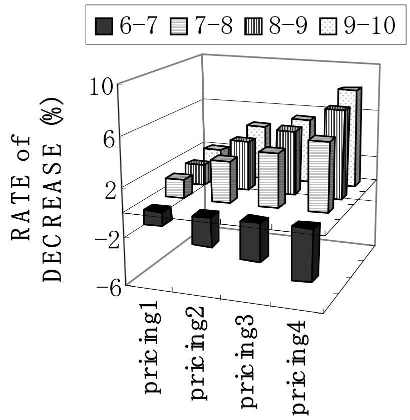

Figure 8. The hourly reduction of NOx emission in the morning.

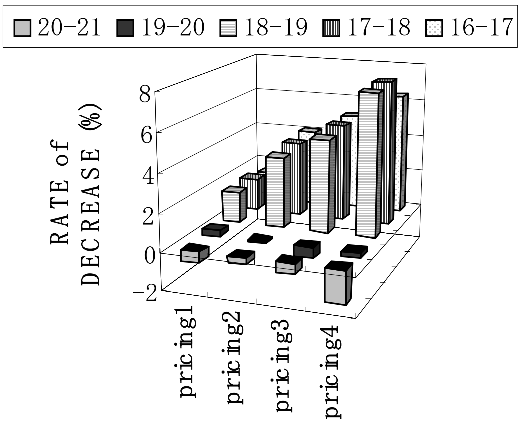

Figure 9. The hourly reduction of NOx emission in evening.

The reduction of hourly NOx emissions over the network as the daily NOx emission, depends on the area of road pricing. Hourly analysis reveals that the increase of hourly NOx emission is expected only one hour prior to pricing hour in the morning but in the evening the increase of NOx emission is expected after two hours of pricing hour. Based on the hourly reduction of NOx emission, it is not easy to determine the best pricing scheme because the larger pricing area shows larger increase before and after the pricing hours.

3.4. The local deterioration of NOx emission due to road pricing.

It is clear that the effects of road pricing should depend on location. The local deterioration of NOx emission per pricing scheme is shown in Figures 10 to 13. 'Local deterioration of NOx emission' is the difference between simulated NOx emission without pricing and per pricing scheme (kg/day). The white zone indicates the area where NOx emission decrease, and the black zone where NOx emission increase. In these figure, the dotted line shows the pricing boundary and the ellipses show the zone where NOx emission increase worst and second worst. Each of RING5-8 indicates #5 & #8 circular traffic roads surrounding the center of Tokyo.

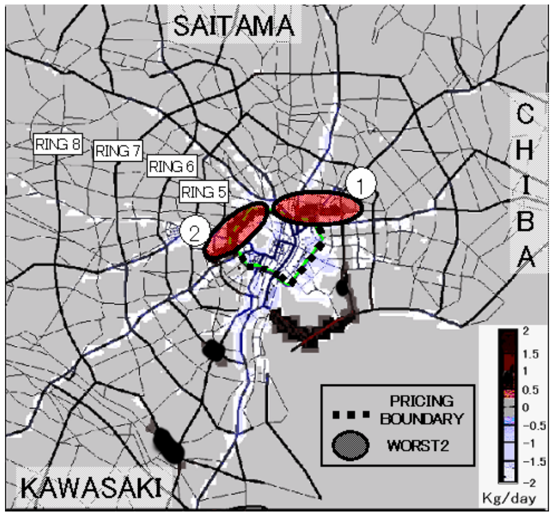

Figure 10. The local effects of the road pricing 1.

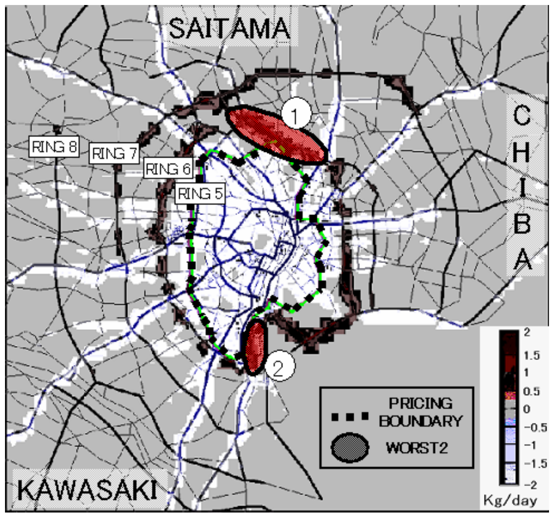

Figure 11. The local effects of the road pricing 2.

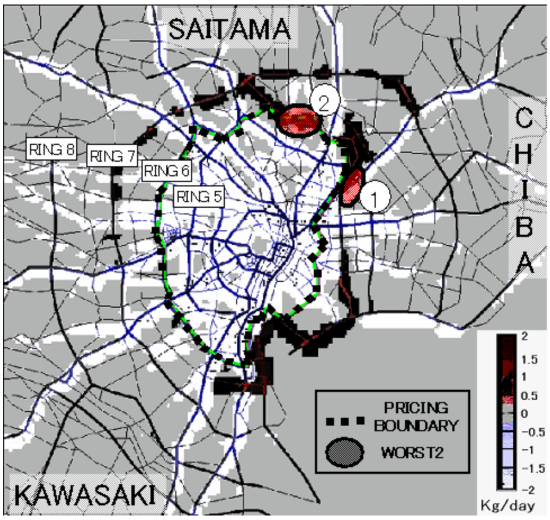

Figure 12. The local effects of the road pricing 3.

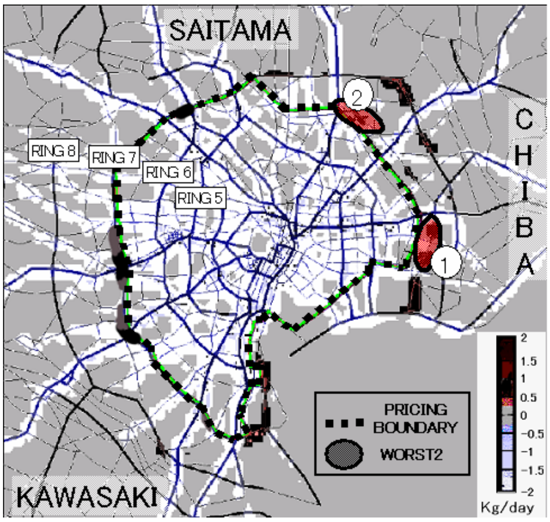

Figure 13. The local effects of the road pricing 4.

According to these figures, the decrease of NOx (white zone) is found over most of the networks, especially inside of the pricing boundary. The increase of NOx emission (black zone) is found on the circular road just beyond the pricing boundary for all kinds of pricing1-4. Next we focus on (black zones) where road pricing increases the NOx emission.

The first, second and average deterioration of NOx emission are shown in Figure 14 for each pricing scheme. Pricing3's large NOx increase is expected for the northeast area; whereas pricing2's NOx increase is more modest. Based on the average increase of the NOx emission within each area, pricing1 and pricing3 are not so good, pricing4 is better and pricing2 is the best. The rate of deterioration, particularly at the two worst areas, is much more than the improvement of every pricing (Table 2). Total improvement is certainly expected after enforcement of road pricing; but partial deterioration should not be ignored, for it is not a small impact.

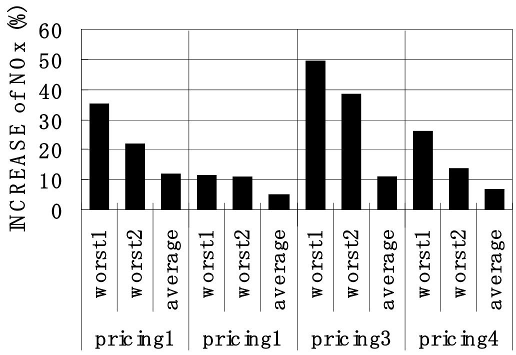

Figure 14. The rate of deterioration

3.5. Road pricing schemes

Road Pricing has two major schemes: area and cordon. The area-pricing scheme applies to everyone within a designated area whilst the cordon scheme applies to vehicles that enter a designated area. The cordon scheme requires a check point at the area's boundary and hence, would be implemented with minimum cost and is more efficient for fee collection. But vehicles within the area are not charged. The area scheme doesn't omit any such vehicles but requires a more advanced and complicated fee-collection system at a greater cost. There is a distance fee-collection system that depends upon the vehicle's mileage within the designated area which doesn't use the current fee-collection technology. Hence the cordon scheme is preferred.

4. CONCLUSIONS

We reproduce the present traffic flow pattern using dynamic-traffic simulation. The traffic-simulation model was verified by comparing the observed and simulated traffic volumes. It was confirmed that our traffic model could be used for evaluating traffic measures such as road pricing.

Pricing 4 is the best pricing scheme for total NOx reduction and pricing scheme 2 is the best scheme for partial deterioration. We need to further verify the validity of HGV behavior; for according to Figure 3, the NOx emission from an HGV is significantly greater than from a small car. Therefore, the total reduction of NOx emissions depends on the HGV drivers' reaction to road pricing.

This study shows where environmental deterioration (NOx increase) would arise and estimate how much deterioration is expected. Based on our research, road pricing scheme 2 is the best when considering the impact of detouring vehicles.

5. ACKNOWLEDGEMENTS

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