ESTIMATION OF OPTIMAL REFUND LEVEL OF PARKING DEPOSIT SYSTEM

by Zhi ZUO[**] Ryo KANAMORI[***] Tomio MIWA[****] Takayuki MORIKAWA[*****]

1. Introduction

Congestion had been more and more serious problem of the metropolitan cities during last decade, both in developing and developed countries, which had lead to heavy air pollution, more accidents and noises. At first, governments tried to construct more facilities to follow the pace of increasing traffic volumes on the road, but it was found in vain to solve the problem, because the speed of construction can not catch the increasing private car ownership. Then researchers and policy makers focused their eyes on another method, transportation demand management (TDM) had been proposed to reduce travel demands, or to redistribute demands in space or in time. As a most effective policy to restrain travel demand, road pricing (RP) receives much attention, a lot of works had been made by researchers both in modeling theory[4)] and practice[5)], but the disadvantage of RP policy is also clear, on one hand, about acceptance, it is hard to be accepted by public because of additional costs to implement the policy[2)], and on the other hand, about economical loss, the pricing area will suffer some socioeconomic activities losses due to the pricing policy of the area.

In order to improve the acceptability of RP, researchers had to propose various methods or proposals to overcome those disadvantages. ANDO[1)], MORIKAWA. *et al*. (2006) proposed an idea of Parking Deposit System(PDS) of road pricing policy, through the questionnaire survey, it shows that PDS is a highly acceptable new form of RP policy and is easier to be accepted by public than general RP policy. KANAMORI[6)] et al (2007) validated effect of PDS restraining travel demand. But it is still not known that how much the refund is with fixed initial toll should we obtain the optimal object when implementing PDS on a network. This paper tries to analyze the characteristic of PDS, constructing a multi-class user equilibrium model of PDS, and estimate the effect of various refund level PDS pricing schemes, through comparing different refund levels of the same initial toll, optimal refund level will be obtained.

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** Student Member of JSCE, Doctor Candinate Graduate School of Civil Engineering, Nagoya University.
(Furo-cho, Chikusa-ku, Nagoya, 464-8603. Tel: 052-789-3730)
*** Member of JSCE, School of Urban Engineering, University of Tokyo.
(3-1, Hongo 7-chome, Bunkyo-ku, Tokyo, 113-8656)
**** Member of JSCE, EcoTopia science institute, Nagoya University.
(Furo-cho, Chikusa-ku, Nagoya ,464-8603, Tel: 052-789-3565)
***** Member of JSCE, Graduate School of Environmental Studies,Nagoya University.
(Furo-cho, Chikusa-ku, Nagoya, 464-8603, Tel: 052-789-3564)

2. Model Formulation

According to the description of PDS policy: PDS does not apply charges to all vehicles entering a given area as is the case with conventional road pricing, but charging only "through traffic" and "illegally parked vehicles" that have a major impact on traffic congestion in downtown areas, drivers who contribute to local economic activities are granted an exemption. We can conclude from the description that for drivers of different trip purpose the travel impendence is different on the same link, as for the user equilibrium problem, we also know if someone has an economical activity, he will make a trip to go somewhere, or "ENTER the objective area". Basing on the assumption that a trip entering the objective area is an economical activity, then the PDS toll model can be constructed as an OD based multi-class traffic user equilibrium assignment model. Following equations are the description of model.

$$\min_{x} Z = \sum_{a\in A}\left\{\int_0^{x_a}\hat{t}_a(w)\cdot dw + \sum_{rs\in\Omega}\frac{\pi_a}{\xi_{rs}}\cdot x_a^{rs}\right\} \quad (1)$$

$S.T.$

$$f_{rs,k} \geq 0 \qquad \forall rs\in\Omega,\quad k\in K \quad (1\text{-}1)$$

$$\sum_{k\in K_{rs}} f_{rs,k} = q_{rs} \qquad \forall rs\in\Omega \quad (1\text{-}2)$$

$$x_a^{rs} = \sum_{k\in K_{rs}} f_{rs,k}\delta_{rs,k}^{a} \qquad \forall a\in A \quad (1\text{-}3)$$

$$x_a = \sum_{rs\in\Omega} x_a^{rs} \qquad \forall a\in A \quad (1\text{-}4)$$

Here,

$f_{rs,k}$: volume on path k between OD pair *r* and *s*.

q_{rs} : OD demand between OD pair *r* and *s*.
x_a : volume on link *a*.

$\hat{t}_a$: travel time on link *a* (without toll option).

π_a : toll value on link *a*.
ξ_{rs} : parameter of value of time.

$\delta_{rs,k}^{a}$: 1-if link *a* is included in the path *k* between OD pair *rs*, 0-otherwise.

A : the whole link set.
K_{rs} : path set of OD pair *rs*.
Ω_a : OD pair set.

x_a^{rs} : volume on link *a* between different OD pairs.

About the algorithm of solving the model, please reference the book Guidebook on Traffic demand and forecasting[4] (Volume II), JSCE, Japan, 2006 for the details of solving OD based multi-class user equilibrium problem.

3. Case study

We made the case study on the Nagoya metropolitan road network, charging area was set at the area of central business district of the city, which are show in Figure 1, black line are road network links and the red line representing the cordon line of charging area, if a driver make trip entering the cordon area, he will be granted the exemption, otherwise, if a driver make only the through traffic trip, he will get no exemption. There are 3 toll levels be set and table 1 shows the levels of toll. As for the refund, we set 10 refund levels of each toll value, distributing from 10 percents to 100 percents of the toll value, and table.2 shows the cases of different refund levels.

Figure 1: Location of pricing area.

Table 1: Toll Levels (YEN)

Toll Level	Value
1	200
2	300
3	500

Table 2: Detail of All Refund Cases

Refund Rate	Toll Levels (YEN)					
	500		300		200	
	Refund	Actual Toll	Refund	Actual Toll	Refund	Actual Toll
10%	50	450	30	270	20	180
20%	100	400	60	240	40	160
30%	150	350	90	210	60	140
40%	200	300	120	180	80	120
50%	250	250	150	150	100	100
60%	300	200	180	120	120	80
70%	350	150	210	90	140	60
80%	400	100	240	60	160	40
90%	450	50	270	30	180	20
100%	500	0	300	0	200	0

4. Result of Case Study

For this OD based multi-class user equilibrium problem, we took the total network time cost as the optimal object. The results of all the cases of 3 toll levels are shown in figure 2, 3, 4 and table 3, 4, 5. From the figures we can know that with the trend of actual toll increasing, network time cost is increasing together, although figure of 200 level had fluctuated twice, the general trend of curve is similar to the other two levels, and during all the 3 toll levels the 90% refund cases received the lowest network time cost.

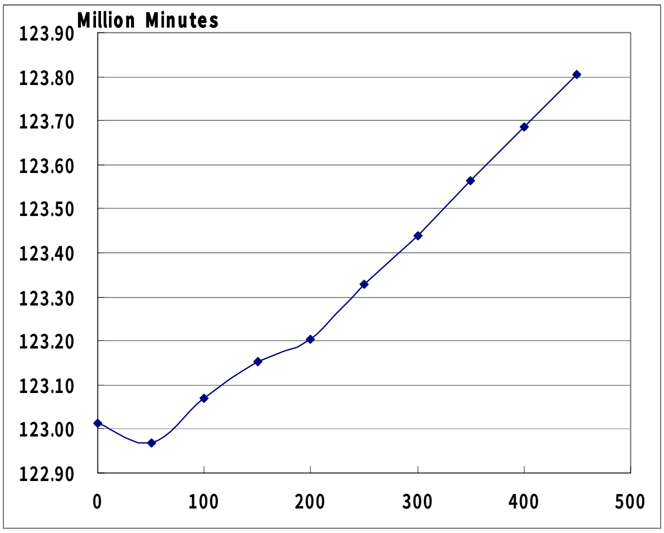

Figure 2: Result of Toll level 500

Table 3: Result of 500 level (Unit: min)

Refund (YEN)	Actual toll (YEN)	Network time cost (minute)
50	450	123803951.78
100	400	123684261.71
150	350	123562561.09
200	300	123439407.88
250	250	123329593.35
300	200	123204226.51
350	150	123152726.23
400	100	123068634.57
450	50	122969041.82
500	0	123014095.77

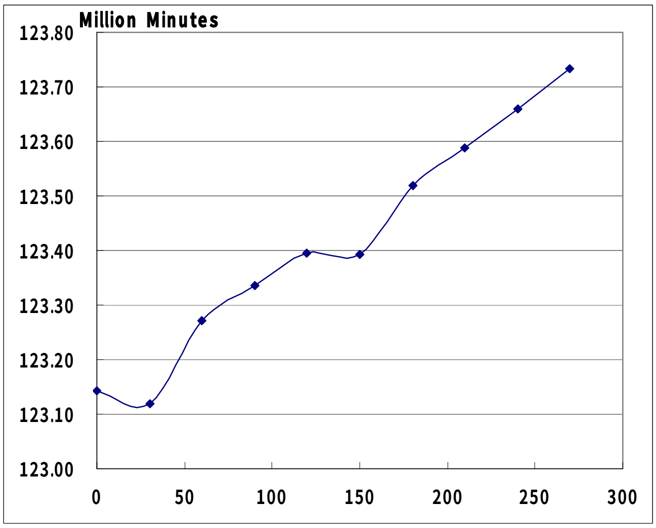

Figure 3: Result of Toll level 300

Table 4: Result of 300 level (Unit: min)

Refund (YEN)	Actual toll (YEN)	Network time cost (minute)
30	270	123733039.06
60	240	123660035.85
90	210	123588868.50
120	180	123518650.16
150	150	123392822.58
180	120	123396186.50
210	90	123335566.64
240	60	123272132.47
270	30	123120107.02
300	0	123142242.24

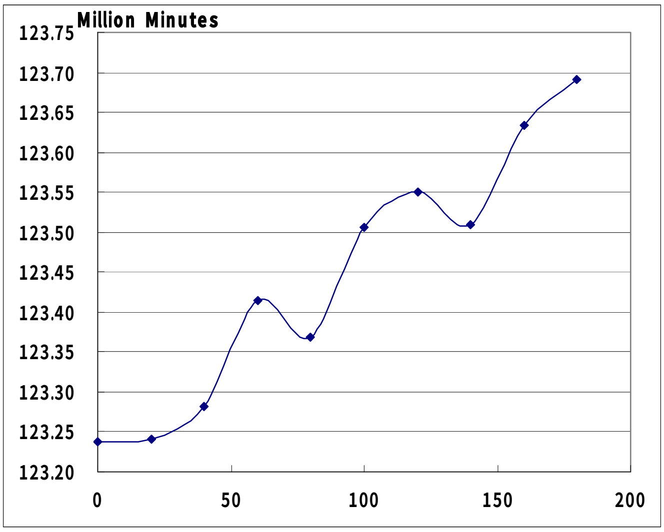

Figure 4: Result of Toll level 200

Table 5: Result of 200 level (Unit: min)

Refund (YEN)	Actual toll (YEN)	Network time cost (minute)
20	180	123691153.16
40	160	123634273.13
60	140	123509362.94
80	120	123551039.85
100	100	123506101.80
120	80	123368382.82
140	60	123414948.87
160	40	123282054.53
180	20	123240379.14
200	0	123237703.30

5. Conclusion and future study.

In this paper, we analyzed the characteristics of PDS policy and an OD-based multi-class user equilibrium traffic model has been applied for the PDS road pricing policy, case studies had been carried on Nagoya metropolitan road network with 3 toll levels and 10 refund separately, the results showed that for all of 3 toll level using the multi-class UE model, similar results are received and the 90 percent refund rate of toll value is supported by the model. Because the limitation of UE traffic model, the OD demand is fixed, no one will choose canceling the trip or shift to another transport mode, in the future study, a more precise model should be constructed for the PDS policy, an OD based multi-class variable demand user equilibrium model will be more adequate for estimating the optimal refund value.

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