Optimal Congestion Pricing based on Bi-Level Model Considering Departure Time Choice in Metro Cebu Philippines

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1. INTRODUCTION

In Cebu Island and Mactan Island of the Philippines which are connected by two bridges, the congestion of the first bridge is more serious than that of the second bridge. By imposing the congestion charge on the first bridge during peak hour, it is expected to shift traffic demand by encouraging change of departure time and route from the first to second bridges. However, the optimal congestion charge price should be calculated as the amount that minimizes the total congestion, taking into consideration changes in user behavior such as departure time and route selection in response to changes in the congestion charge amount.

The main objective of this study is to calculate the optimal congestion pricing based on Bi-level Model. The secondary objectives are to develop and validate the integration of departure time choice model and optimal congestion pricing model for Cebu city and evaluate the impact of the integrated model on urban traffic.

2. OUTLINE OF MODEL

In this study, the optimal congestion charge is formulated by bi-Level model.

2.1 Lower-Level Model

In the lower level of the model, assigned traffic is obtained by typical traffic assignment model. In this study, this process was calculated by the path choice model and departure time choice model of VISSIM simulation.

The multinomial logit model applied to the departure time change model to determine the probability P of an individual q selecting choice i from j alternatives are as follows:

$$P_{iq} = \frac{e^{U_{iq}}}{\sum_{j=1}^{J} e^{U_{iq}}} \quad (1)$$

According to the specific situation of the Metro Cebu city's congestion, two bridges connecting the Cebu Main Island and Mactan Island were selected as the research section to do the SP survey. The survey was conducted among people who frequently use the first bridge in their lives, and they were asked about their opinions and prices on introducing congestion pricing on the first bridge. The toll section was the first bridge, the free section was the second bridge.

The utility function of departure time choice was estimated by the SP survey as follows,

$$\begin{aligned} U_{Departure} = {} & 187.4 + 11.769\, Education + 26.916\, Gender \\ & -13.560\, Car\ Traveled - 0.188\, Income \\ & -9.463\, Travel\ Time - 7.374\, Toll \end{aligned} \quad (2)$$

2.2 Upper-Level Model

The upper level of the model searches for the optimal congestion pricing strategy increases the utilization rate of roads and reduces traffic congestion from the perspective of the optimal system.

The simulation runs will stop until finding the optimal congestion pricing, the equations of the Upper-Level Model as follows:

$$F_1 = \sum_a x_a * t_a \quad (3)$$

$$F_2 = \sum_a x_a * u_a \quad (4)$$

$$Max\ F\,(x,u) = \sum_a x_a * u_a - \sum_a x_a * t_a \quad (5)$$

S.t.

$$\min \begin{Bmatrix} X_{First\ Bridge} * T_{First\ Bridge} - X_{First\ Bridge} * Toll \\ - \times X_{First\ Bridge} * T_{Second\ Bridge} \end{Bmatrix} \quad (6)$$

$$x_a \le C_a, 0 \le u_a^{min} \le u_a \le 0 \le u_a^{max}, \forall a \in A \quad (7)$$

$$u_a = 0\ \forall a \notin A \quad (8)$$

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Where,

A = the set of links in the network, x_a= the flow on the link $a \in A$, t_a= travel time on link $a \in A$, C_a= capacity of link $a \in A$, u_a= Toll on the link $a \in A$, Toll= Congestion Pricing, $X_{First\ Bridge}$ and X_{Fernan} represents the traffic flow on First bridge and Second Bridge, $T_{First\ Bridge}$ and $T_{Second\ Bridge}$ stands for the travel time on the First bridge and Second Bridge.

From the perspective of the upper management, the goal of congested road pricing is to optimize the performance of the entire network system. Indices that are usually used to measure the performance of the road network are (1) network total minimum cost (equation 3) and (2) network total maximum benefit (equation 4). The larger the difference between the network total cost and network total benefit, the larger the realized network benefits and the smaller the network costs.

3. SIMULATION AND RESULTS

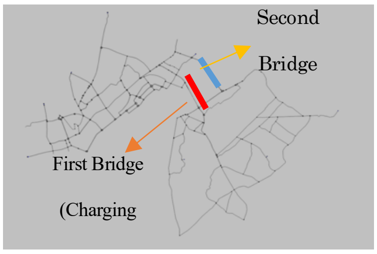

Figure 1. Study Area

3.1 SCENARIOS

In this study 4 different scenarios were setup to determine the optimal congestion charging on the first bridge. The first scenario will have no charge, the second scenario charges 10 peso, the third scenario charges 50 peso and the fourth scenario charges 100 peso. These simulations were run on VISSIM.

3.2 RESULTS

Figures 2 and 3 showed the trend of the VHT and VKT in each scenario. Based on Figures 4 and 5, it could be seen that the traffic volume of the First Bridge begins to balance that of the Second Bridge and, the Delay Time on the First Bridge was reduced while on the Second bridge increased slightly.

The delay time of the first bridge decreased at the 100 peso congestion charge and the VHT and VKT of the whole network performance also decreased significantly compared to the 50 peso congestion charge. According to Figure 5, the first bridge and the second bridge has maintained a convergence regarding their respective traffic volumes, considering the first bridge is only two-way two lanes while the second bridge is two-way four lanes, the delay time of the first bridge is still greater than the results of the second bridge. However, it is important to understand that the higher pricing on the first bridge the fewer people will choose that exact bridge, which results in people taking a longer way to go to their destination and causing the network to worsen. Hence, it is more reasonable to charge 50 peso than 100 peso.

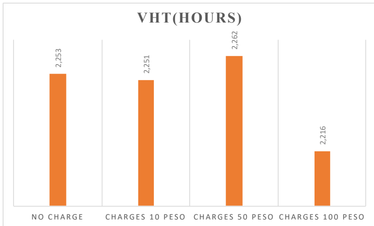

Figure 2. VHT (Network Performance)

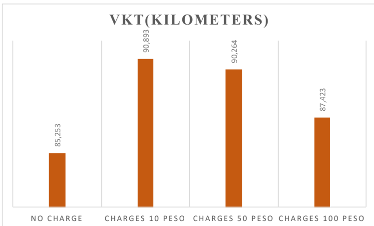

Figure 3. VKT (Network Performance)

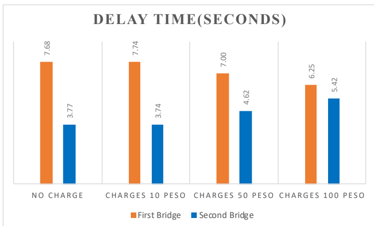

Figure 4. Delay Time on Bridges

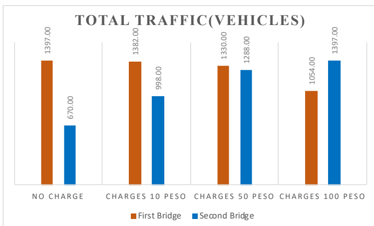

Figure 5. Total Traffic on Bridges

4. CONCLUSIONS

This study established the bi-level model of congestion pricing based on VISSIM simulation and gave an optimal charge level considering departure time.

5. REFERENCE

1) Yao, Yan, Chen. Simulation-based optimization for urban transportation demand management strategy.