Study on Congestion Pricing Considering Departure Time and Route Choice Behavior in Metro Cebu, Philippines

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The policy of congestion pricing is proposed to solve the problem of imbalanced traffic flow in time and space coming from different directions according to traffic demand. The congesetion pricing was evaluated as the case study of the first bridge in Mactan, Metro Cebu. The Simulation software-VISSIM was used to simulate and evaluate the network performance and the delay time and total traffic volume under different states of the congestion pricing. As a result, the vehicle hours traveled (VHT) was decreased by 6% and delay time on the first bridge was also decreased by 63.3% and vehicle kilometers traveled (VKT) was increased by 1.3%. It was concluded that the congestion pricing has postive impact to reduce traffic congestion.

Key Words : *congestion pricing, route choice, departure time choice, sp survey, vissim*

1. INTRODUCTION

Cebu city is comprised of Cebu mainland and Mactan Island, as the population increases the city is also extending. Cebu mainland covered the CBD, administrations, commercial and residential area, while Mactan Island only contained residential and airport zones. To provide better mobility in the city, transportation infrastructure plays critical role. However, Cebu mainland and Mactan Island is only connected by two bridges i.e., First Bridge and Second Bridge bridges. First Bridge is a 2-lane bridge with one lane per direction and Second Bridge is a 4-lane bridge with 2 lanes per direction. As the traffic increases between both lands, the infrastructure is deemed to be insufficient, indicated from the heavy traffic congestion it causes. To counter this problem author proposed to introduce the policy of congestion pricing on First Bridge bridge because the traffic congestion happens during peak hours and in a one direction (i.e., during morning peak traffic direction is from Mactan Island to Mainland, while the opposite direction is free). The author selected First Bridge bridge rather than Second Bridge bridge due to the fact that First Bridge bridge is located in the center of both lands.

By imposing a congestion charge on the first bridge during peak hours, it is expected to shift traffic demand, encouraging a change of departure time, and route choice from the first to the second bridge. However, the optimal congestion pricing should be calculated as the amount that minimizes the total congestion, by taking into consideration the 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 by considering departure time choice and route choice. The secondary objective is to develop and validate the optimal congestion pricing model for Cebu city and evaluate the impact of the integrated model on urban traffic.

2. LITERATURE REVIEWS

Congestion pricing, also known as congestion charging, was first proposed by Pigou (1980) in the book "Welfare Economics" (1920): if it charged on one road, the result was that the speed of vehicles on the toll road was much better than the no-toll road.

Based on the congestion charging, Wang Jian et al. (2010) established a bi-level model of traffic congestion pricing. The upper level was built to minimize the crowding degree of the traffic network, and the lower was the user equilibrium of fixed demand. The genetic algorithm was used to analyze and solve the case and obtained the reasonable congestion rate.

Cheng Tiexin et al. (2014) took the domestic urban central area network as the object, then using VISSIM software established the urban central area pricing model. This approach finally gave a satisfactory pricing scheme and corresponding signal scheme.

Sun Xin (2015) proposed a distance-based congestion pricing optimization bi-level programming model. The upper level was a multi-objective optimal model, while the lower level was a user equilibrium model. The genetic algorithm was adopted to deal with multi-objective problems. It has been proved that the distance-optimal congestion charging function was highly non-linear which could optimize the network system.

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Baozhen Yao (2018) proposed a Bi-level model to optimize urban TDM strategies based on simulation. Peng (2003) implemented one of the most expensive road pricing projects that resulted to increase traffic speed by 37%, dropping the congestion by 40% during charging hours and reducing round-trip travel time by 13%, only 8 months after implementation of road pricing.

This study develops the congestion pricing considering the departure time choice change and route choice change by the SP survey and uses both the stated preference survey and the network level microsimulation to determine the optimal congestion pricing.

So far, there are Toronto, London, Singapore, and other cities who apply congestion charges on their motorists (Table 1). Among them, Singapore was the first country implemented the congestion charge on a large scale.

Table 1 Overveiw of congestion pricing

City	Scope of Charges	Core Technology	Basic Objectives
London	Urban core area	Number Plate Recognition	Ease traffic jams
Singapore	City center	DSRC's ERP System	Traffic Demand Management
Toronto	407 Highway	DSRC	Ease road congestion

3. METHOLOGY

In this research, a questionnaire survey on departure times and route selection in central Cebu, including Mactan Island and the opposite bank was firstly conducted. Based on the results of the survey, a model that simulates the state of traffic across two bridges was developed when toll was charged at the bridge. The relationship between the toll and VKT/VHT was finaly analized.

(1) Study area

As mentioned in the introduction, the First Bridge and Second Bridge connected between the Cebu mainland and Mactan as shown in the Figure 2, Traffic congestion occurs on the First Bridge from Mactan Island to Cebu Island during the morning rush hour.

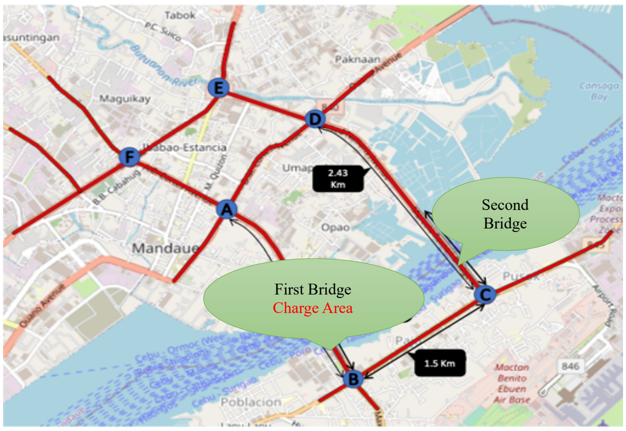

Fig.2 Study area.

Two bridges connect Cebu Island and Mactan Island. The study area was selected as one of the Two bridges, called the First Bridge. First Bridge has only two lanes with no distinction between motorized lanes and non-motorized vehicles.

Peak hour east direction and west direction traffic data are shown in Table 2.

Table 2 Traffic volume and directional distribution coefficient

Morning Peak Time (8:00-9:00)	To Cebu	To Mactan
Traffic volume (Veh/h)	3,122	972
Directional distribution coefficient	0.77	0.23

(2) DEpating Time and Route Choice Survey

The survey area was divided into two sub-areas: Cebu city, Mactan island. The survey is divided into two parts: Part I of the survey aims at collecting information about the travel behavior before and after congestion pricing implementation, while Part II collects data on the actual travel behavior in response to congestion pricing. The results from both parts are analyzed together to provide a comprehensive picture of how people respond to congestion pricing.

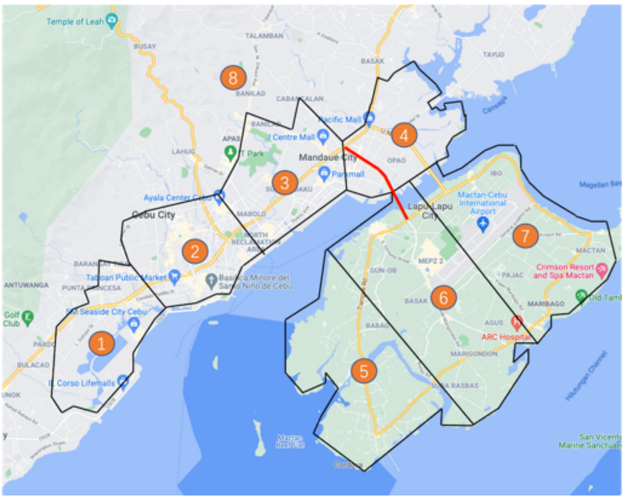

Fig.3 Survey area.

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 study area to conduct the SP survey.

The survey was conducted among people who frequently use the first bridge in their lives, and they were asked about their preferences in the changes of route choice and/or departure time choice under the different scenarios of the introduction of congestion pricing on the first bridge.

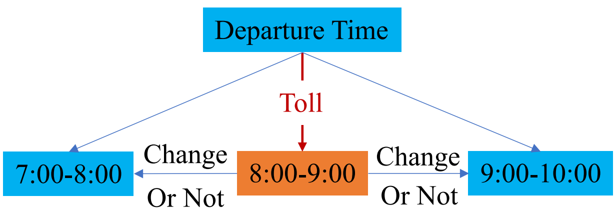

Fig.4 Departure time changes survey design.

For the departure time change question design, only from 8:00-9:00AM this time interval was charged by different levels of congestion pricing, and assumed that working time start from 10:00 AM, the question design was expected to clear the departure time change before and after implementation of different states of congestion pricing.

The behavior change of route choice was design as shown in Figure 5.

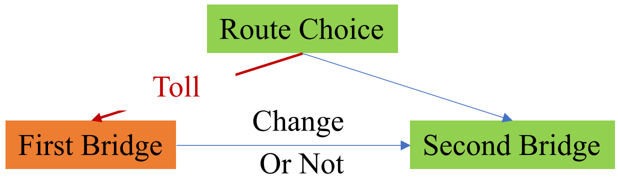

Fig.5 Route choice changes survey design.

The toll section was the first bridge during the morning peak hour (8:00-9:00 AM), the free section was the second bridge.

The equation used for the parameter estimation are as follows,

$$u_A = \sum i \, \beta_{A,i} \cdot x_i \tag{1}$$

$$p_A = \frac{\exp(u_A)}{\sum i \exp(u_{A,i})} \tag{2}$$

Where u_A stands for the utility for choice A, x_i is the attributes and β is the corresponding parameters.

(3) Basic Concept of Model

The Whole framework consists of two parts, part one includes survey analysis, which was used to estimate the parameters of departure time choice and route choice models.

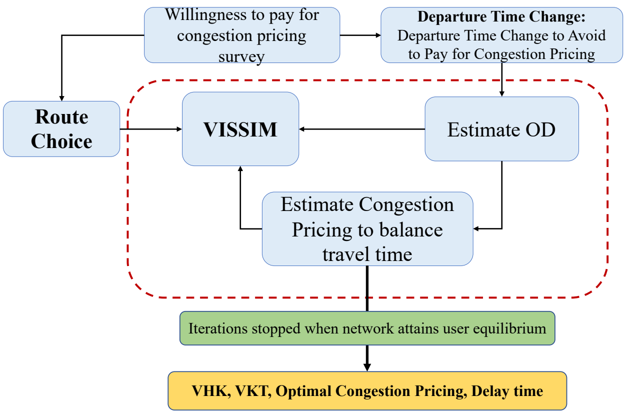

Fig.1 Overall research framework.

Part two is the simulation-based traffic assignment by micro simulation software VISSIM, the estimated departure time choice and route choice model were used in VISSIM to change traffic behaviors, simulation of the base and different congestion pricing scenarios was also done at this stage.

In general, data was gathered to act as the input of the model and the model was run to simulate the results of the base, congestion pricing scenario model.

The result of the traffic assignment will be further analyzed in order to express the effect of each policy.

(4) Departure time choice model

In the departure time choice model, OD matrix was estimated. The result was fed into VISSIM, and simulation was run in order to analyze the sensitivity of different pricing in congestion charge. The departure time choice model was estimated using the SP survey with the following formula,

$$\frac{\ln P_{Depart\ Early}}{P_{Departure\ No\ change}} = 1.633 + 0.2 \cdot Comfort \\ -0.22 \cdot Travel\ Time - 2.552 \cdot Congestion\ Pricing \quad (3)$$

$$\ln \frac{P_{Depart\ Early}}{P_{Departure\ Time\ No\ Change}} = -1.883 + 0.13 * Comfort \\ -0.93 * Travel\ Time - 3.905 * Congestion\ Pricing \quad (4)$$

Table 3 Coefficients of variables and P values of departure time choice model

	Departure time Change (Early)		Departure time Change (Late)	
Variables	Coefficient	Significance	Coefficient	Significance
Constant	1.633	0	-1.883	0
Comfort	0.2	0.047*	0.13	0.022*
Travel Time	-0.22	0.038*	-0.93	0.038*
Congestion Pricing	-2.552	0.000***	-3.905	0.000***

*: 0.01<P<0.05, **: 0.001<P<0.01, ***:P<0.01

(5) Route choice model

In VISSIM, assigned traffic is obtained by typical traffic assignment using the theory of user equilibrium, which involved a route choice model. The route choice model was calculated by applying a multinomial logit model.

A survey was conducted in order to estimate parameters for the route choice model. The formula used for the choice model is a typical utility and probability function as shown in the Equation (5) and (6) in the next chapter. With the corresponding attributes and variables, the probability for choosing which route is the best was calculated using the Equation (1) and (2),

$$U_{First\ Bridge} = (\beta_1 \cdot Constant_{value}) \\ +(\beta_2 \cdot Travel\ Time) \\ +(\beta_3 \cdot Congestion\ Pricing) \quad (5)$$

$$U_{Second\ Bridge} = (\beta_1 \cdot Constant_{value}) \\ +(\beta_2 \cdot Travel\ Time) \quad (6)$$

Table 3 Coefficients of variables and P values of route choice model

	First Bridge		Second Bridge	
Variables	Coefficient	Significance	Coefficient	Significance
Constant	3.462	0	1.473	0
Travel Time	-0.946	0.05*	-1.296	0.033*
Congestion Pricing	-1.506	0.046*	-	-

*: 0.01<P<0.05, **: 0.001<P<0.01, ***:P<0.01

In this study only travel time was considered as the significant variable that contributes to the departure time choice and route choice, it is necessary to consider other factors such as fuel cost and mode choice in the future.

4. SURVEY RESULT

The results of the survey were organized and analyzed to clarify the responds of the travelers due to the implementation of the policy, Figure 6 shows the behavior of changing the route under different level of congestion pricing (charged route is only the First Bridge).

Figure 7 demonstrates the responds of departure time choice under the same policy, where people tend to move their departure time earlier as the charging goes up.

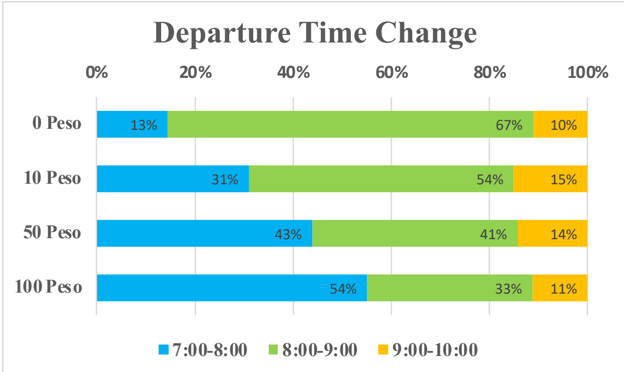

Fig.6 Departure time changes.

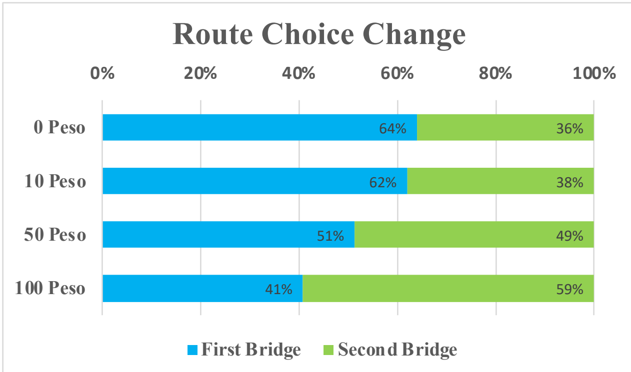

Fig.7 Route choice changes.

5. MODEL SIMULATION

The whole size of the network is 16 km by 12 km, and simulation time was set up during 7:00 – 9:00 AM with charged area being 8:00 – 9:00AM. Simulation for the base case and different scenarios with different congestion charges of 0, 10, 50, 100, 150, 200 Pesos were run on VISSIM.

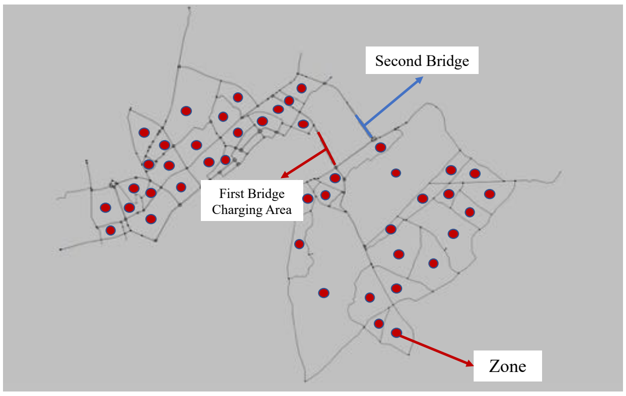

Fig.8 Nework model.

(1) Scenarios

In this research, 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 Pesos, the third scenario charges 50 Pesos and the fourth scenario charges 100 Pesos, the fifth scenario charges 150 Pesos and the sixth scenario charges 200 Pesos.

(1) Simulatino results

Figures 9 and 10 showed the trend of the Total Delay and number of vehicles in each scenario. Based on Figure 9 and 10, 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.

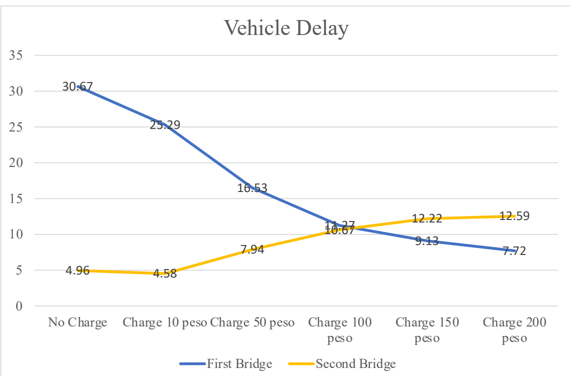

Fig.9 Delay time on bridges.

With the increase of the congestion pricing (100 Pesos), the delay of the first bridge decreases by 63% compared to no congestion pricing, considering that the second bridge is two lanes in both directions, which can carry more vehicles compared to the two lanes in both directions of the first bridge.

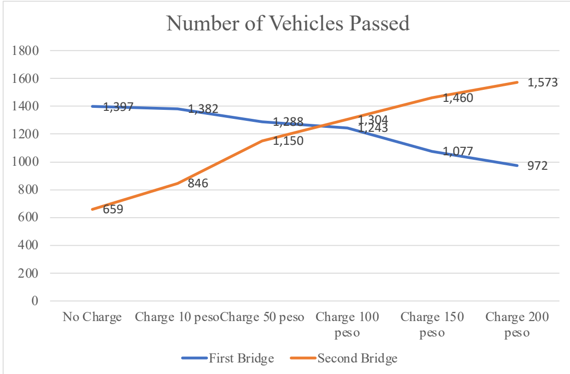

Fig.10 Total traffic on bridges.

Figures 11 and 12 present information concerning traffic indices including vehicles kilometers traveled (VKT), vehicles hours traveled (VHT) within the network. Total number of VHT in the network decreased while VKT increased with the implementation of congestion pricing charging 100 Pesos. This had a positive impact on traffic flow and significantly improved network mobility.

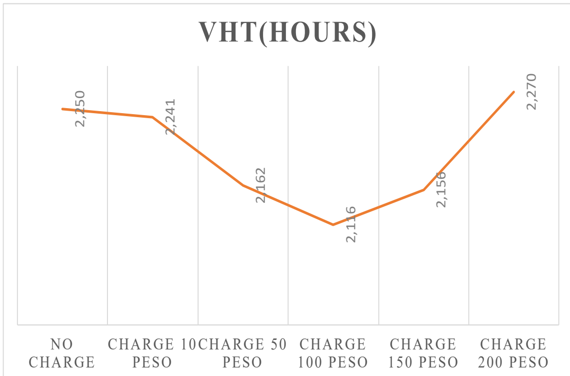

Fig.11 Vehicle hours traveled.

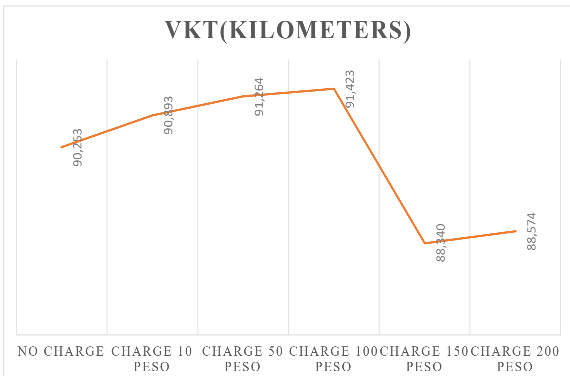

Fig.12 Vehicle kilometers traveled.

Compared to the congestion pricing scenarios of

150 Pesos and 200 Pesos, VHT has increased significantly and VKT has decreased. Therefore, according to the results of network performance, the optimal congestion pricing was considered as 100 Pesos.

Table 4 Volume shifted under various congestion pricing

	Scenarios (Peso)	Volume					
		First Bridge			Second Bridge		
		7:00-8:00AM	8:00-9:00AM	9:00-10:00AM	7:00-8:00AM	8:00-9:00AM	9:00-10:00AM
Cebu to Mactan	0	1691	1528	1298	1125	815	807
	10	1682	1502	1285	1209	929	914
	50	1590	1436	1220	1294	1057	1028
	100	1370	1238	1051	1358	1110	1079
	150	1096	990	841	1766	1443	1403
	200	767	693	589	2119	1731	1684
Mactan to Cebu	0	1944	1688	1397	1113	1222	1061
	10	1860	1664	1382	1166	1338	1091
	50	1776	1604	1363	1211	1236	1018
	100	1420	1284	1090	1454	1484	1221
	150	1136	1027	872	1890	1929	1587
	200	795	719	611	2267	2314	1905

Table 5 Total Volume shifted on first bridge

Scenarios (Peso)	Total Volume Shifted on First Bridge			
	Cebu to Mactan	%Change	Mactan to Cebu	%Change
0	4517	/	5029	/
10	4469	-1%	4906	-2.45%
50	4246	-6%	4743	-5.69%
100	3659	-19%	3794	-24.55%
150	2927	-35%	3035	-39.64%
200	2049	-55%	2125	-57.75%

Table 6 Total Volume shifted on second bridge

Scenarios (Peso)	Total Volume Shifted on Second Bridge			
	Cebu to Mactan	%Change	Mactan to Cebu	%Change
0	2747	/	3396	/
10	3052	11%	3595	5.86%
50	3379	23%	3465	2.03%
100	3548	29%	4158	22.44%
150	4612	68%	5405	59.17%
200	5534	101%	6486	91.00%

According to Table 4, 5 and 6, the first bridge and the second bridge maintain convergence in terms of their respective traffic volumes when charged 100 Pesos. However, it is important to understand that the higher the pricing of the first bridge, the fewer people will choose that bridge, which balances the traffic demand on both bridges. The optimal situation is to solves the traffic congestion on the first bridge and does not worsen the condition on the second bridge. Therefore, it makes more sense to charge 100 Pesos.

5. CONCLUSION

In this research, the relevant measures and model application of congestion pricing on a bridge in Metro Cebu, Philippines were established by toll model based on VISSIM simulation, and analysis of the support data.

The result of the total delay and vehicle arrived of the network performance and delay time and total traffic on the two bridges under various charge levels were analyzed and compared to give an optimal charge level.

The specific implementation effect will make an overall understanding of the traffic congestion charges for policymakers, and a general foreshadowing for the possible pre-feasibility study of Metro Cebu urban congestion pricing.

It is necessary to consider more about the factors of influencing the route choice and departure time change such as fuel cost and mode choice, it is also noteworthy to implement a dynamic congestion pricing policy in the future.

REFERENCES

1) Benson and Peter.: What the Philippines can do to Attract Private Investment in Badly Needed Infrastructure Projects – Focusing on Toll Road: A presentation made at the American Chamber and the Joint Foreign Chambers, 2008.
2) B Yao., Q Yan., Q Chen.: Simulation-based optimization for urban transportation demand management strategy, Simulation: vol.94, no.7, pp.637-647, 2018.
3) Peng, S., Colin, J.: Road user pricing could help ease and manage international traffic congestion, Deloitte and Touche LLP, United States, 2003.
4) Pangilinan, L.: Planning for a better public transportation system to combat gridlock, 15th Annual Conference of the TSSP, Mandaluyong City, Philippines, 2007.
5) Diaz., Crispin Emmanuel.: A Framework for Determining the Viability of Public-Private Partnerships for Toll Road Projects in the Philippines, 2009.
6) Fellendorf M and Vortisch P.: Microscopic traffic flow simulator VISSIM. In: Barcelo´ J (ed.) Fundamentals of traffic simulation. Springer: New York, pp.63–93, 2010.
7) Zhang L, Wang YP, Sun J, et al.: The sightseeing bus schedule optimization under park and ride system in tourist attractions, 2016.
8) Aparajita Chakrabartty, Sudakshina Gupta.: Estimation of Congestion Cost in the City of Kolkata— A Case Study, Current Urban Studies, 3, 95-104, 2015.
9) Schwartz JD, Wang W and Rivera DE.: Simulation-based optimization of process control policies for inventory management in supply chains. Automatica, 2006.
10) Santos G. and B. Shaffer.: Preliminary results of theLondon congestion charging scheme, Public Works Management & Policy, 9, 164-181.2004
11) Mackie, P.J., M. Wardman, A.S. Fowkes, G. Whelan, J.Nellthorp and J.J. Bates.: Values of travel time savings in the UK, Report to Department of Transport, Institute for Transport studies, University of Leeds and John Bates Services, Leeds and Abingdon,2003
12) Wang, Jian, Wei, Chong, Hu, Xiaowei.: Research on congestion pricing rate based on network congestion degree.Highway Engineering, 35(6):92–95, 2010