Effects Evaluation of Eco-driving Behaviors on Urban Intersection Based on Microscopic Simulation Model

Yuyan Zhou[1,*] and Enjian Yao[2]

[1]School of Traffic and Transportation, Beijing Jiaotong University, Beijing, China

[2]MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing, China

*Corresponding author

Abstract—**Compared to usual driving styles, eco-driving is an ecological driving way aiming to reduce emissions and fuel consumption which has received lots of concerns since its emergence. Many studies have shown that eco-driving does bring environmental benefits for individual vehicles in varying degrees. However, the efficiency of eco-driving in terms of the global view of the traffic flow still remains to be studied due to the interaction between eco-driving vehicles and the ones with normal driving styles. In this study, an eco-driving field experiment was conducted first and driving data was collected. An integrated microscopic simulation platform was built by combining the calibrated VISSIM microscopic simulation model and the fuel consumption model; then the impacts of eco-driving behaviors on the test intersection were analyzed. The before-and-after comparison of the evaluating indicators under different traffic scenarios shows that the effects of eco-driving on the intersection are strongly related to the traffic conditions.**

Keywords-eco-driving; microscopic traffic simulation; calibration

I. INTRODUCTION

There is a great concern worldwide about reducing fuel consumption and emissions. Evidences show that road transportation is one of the main contributors to the fuel consumption as well as GHG emissions. Road transportation also implies a great potential in reducing emissions and fuel consumption [1]. Recently, a change in driving behaviors to promote fuel efficiency and reduce emissions which is known for "eco-driving" has attracted more and more interests.

Eco-driving includes various driving behaviors and vehicle maintaining measures according to the GOLDEN RULES [2]: "Anticipate Traffic Flow; Maintain a steady speed at low RPM; Shift up early; Check tyre pressures frequently at least once a month and before driving at high speed and consider any extra energy required costs fuel and money".

This paper presents a method to analyze the effects of eco-driving in one urban intersection under different traffic scenarios and eco-driving penetration rates. First, we conducted a field experiment in which we obtained driving data for further analysis and model calibration. Then, an integrated microscopic simulation platform was built by

combining the calibrated VISSIM microscopic simulation model and a fuel consumption model based on VSP (Vehicle Specific Power). Eco-driving behavior was simulated under different traffic demand and eco-driving penetration rates. At last, we conducted an analysis of different eco-driving scenarios, focusing on fuel consumption and travel time.

II. DATA COLLECTION AND ANALYSIS

A. Experiment

The experiment was conducted during the period from 11 March to 17 April, 2013, in Madrid, Spain. The test vehicle ran through the chosen route 50 times on working days under dry weather condition. The chosen route is urban type and has length of 7.39km. Each trip was driven twice by the same driver: once with normal driving behavior and the second following the "Golden Rules" of eco-driving mentioned above which are also described in the TABLE I. An on-board logging device was used to record second-by-second driving data as well as position coordinates. Then, the driving data within the scope of the selected intersection was extracted from the original database for the following modeling process.

TABLE I. MAIN RULES OF ECO-DRIVING AND DESCRIPTION INDICATOR

Eco-driving rules	Indicator	Abbreviation
Maintain a steady speed	Positive Kinetic Energy	PKE
Anticipate traffic flow	Number of stops per kilometer for speed<5 km/h, Average of negative accelerations	Nst, Aave-
Acceleration smoothly	Average of positive accelerations	Aave+

The chosen single signalized intersection has four legs with the main street of Avenida de la Reina Victoria running west-east which is excluded for left turn and the branch street of Calle de Orense running north-south. The main street carries a heavy traffic volume of 2400 pcu per hour.

B. Data Analysis

To verify the effects of adopting eco-driving advice, the pre-analysis of collected data is made. The results are summarized in TABLE II.

TABLE II. ANALYSIS OF ECO-DRIVING BEHAVIOR ON DIFFERENT INDICATORS

Indicators	Description	Normal drive	Eco-driving	Variation (%)
Vave	Average speed (km/h)	21.438	21.577	0.7%
Vsd	Standard deviation of speed (km/h)	19.066	18.418	-3.4%
Aave+	Average of positive accelerations (m/s²)	0.631	0.508	-19.5%
Aave-	Average of negative accelerations (m/s²)	-0.578	-0.451	-22.0%
Nst	Number of stops per kilometer for speeds lower than 5 km/h	2.269	2.033	-10.4%
PKE	Positive Kinetic Energy	70.827	54.247	-23.4%
RPM	Average of RPM (rpm)	1221.532	1090.01	-10.8%
Fuelave	Average of fuel consumption (l/100km)	6.721	5.910	-12.1%

As shown in the TABLE II, the significant reductions of four indicators related to the eco-driving instructions imply that the eco-driving experiment has a good accordance with the "Golden Rules" above. Furthermore, a great reduction in fuel consumption proves that the eco-driving behavior does bring positive impacts on the individual vehicle.

III. DEVELOPMENT OF MICROSCOPIC SIMULATION MODEL

A. Calibrate of Simulation Model

In order to analyze the effects of eco-driving on the traffic flow, it is impossible to design a field trial involving all the vehicles in the intersection. Traffic simulation model has a clear advantage here allowing users to design different traffic scenarios. In this study, an existing traffic simulation model is chosen and to ensure the accordance of simulation results and real world data, the calibration of key parameters is conducted. This step also defines eco-driving behavior in terms of fuel consumption results avoiding the complexity of design car following rules in the micro level.

Due to the research scope of intersection in this study, a microscopic traffic model needs to be chosen. VISSIM is considered to have more detailed traffic control with a microscopic model based on drivers' behaviors and time-step analysis. However, the simulation with default parameters shows that there are big differences between real world measurements and simulation results. Thus, the calibration of simulation model according to the real measured data is done first to make sure the simulation results could reflect real traffic situation as far as possible.

The calibration parameters in VISSIM can be divided into car-following parameters, lane-change parameters, simulation resolution and desired speed distribution [8]. To narrow the range of calibration, some parameters which have no significant impacts on fuel consumption should be excluded.

According to Li's research [9], the desired speed and acceleration are defined as distributions rather than a fixed value, so they need to be calibrated first. Then, a sensitivity analysis of other parameters is carried out to identify those have significant impacts on fuel consumption. The ANOVA result is as follow:

TABLE III. ANOVA ANALYSIS RESULTS

Parameters	Range	F Value	P-value	Significance
Average standstill distance(m)	[1,4]	1.762	0.176	NO
Additive part of desired safety distance(m)	[1,5]	8.405	0.000	YES
Multiple part of desired safety distance(m)	[1,5]	3.943	0.016	YES
Number of observed preceding vehicles	[1,5]	1.534	0.231	NO
Min headway(m)	[0.5,4]	0.052	0.995	NO

* Significance level=0.05

From above, only additive part and multiple part of desired safety distance are recognized to have strong impacts on fuel consumption and they are selected as the parameters to be calibrated. The calibration results are as follows:
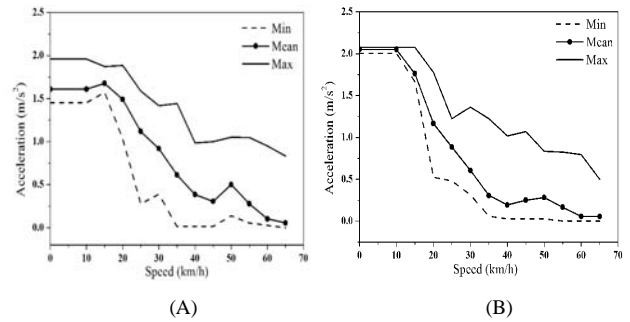

(A)　　　　　　　　(B)

FIGURE I. RESULTS OF ACCELERATION FUNCTION FOR NORMAL DRIVING(A) AND ECO-DRIVING(B) AFTER CALIBRATION

TABLE IV. CALIBRATION RESULTS FOR DRIVING BEHAVIORS

Parameters	Default	Calibrated (normal drive)	Calibrated (eco-driving)
Desired speed distribution(km/h)	40-55	36-72	40-70
Additive part of desired safety distance(m)	2	3.59	4.31
Multiple part of desired safety distance(m)	3	3.00	3.53

B. Establish of Fuel Consumption Model

In order to analyze the impacts, especially the environmental impacts of eco-driving strategy on the intersection, we built an integrated microscopic simulation platform by integrating the VISSIM microscopic simulation model and fuel consumption model based on Vehicle Specific Power (VSP). VSP is defined as the instantaneous power per

unit mass of the vehicle. It is the key factor reflecting the impacts on vehicle fuel consumption. The second-by-second VSP value can be calculated by the following simplified function for light-duty gasoline vehicles [13] in Eq. (2). To describe the relationship between VSP and fuel consumption more clearly, VSP values are designated into different VSP Bins according to Eq. (3).

$$VSP_i^j = v_i^j(1.1a_i^j + 0.132) + 0.000302v_i^{j3} \quad (1)$$

$$VSPBin = n, \forall : VSP \in (n - 0.5, n + 0.5] \quad (2)$$

where VSP_i^j is the ith second VSP value of jth vehicle; v_i^j is the ith second instantaneous speed of jth vehicle; a_i^j is the ith second acceleration of jth vehicle; n is an integer.

The fuel consumption rate under each VSP Bin is calculated as Eq. (4).

$$F_i = \frac{1}{n_i}\sum_{j=1}^{n_i} f_j^i \quad (1)$$

where F_i is the fuel consumption rate under the ith VSP Bin, f_j^i is the collected fuel consumption of the jth second under the ith VSP Bin, n_i is the total number of data samples included in the ith VSP Bin, j is the jth data sample under the ith VSP Bin.

Then, the total fuel consumption can be calculated as Eq. (5).

$$F = \sum_{i=1}^{p} n_i F_i \quad (2)$$

where p is the total number of VSP Bins.

IV. ANALYSIS OF ECO-DRIVING IMPACTS UNDER DIFFERENT SCENARIOS

The impacts of eco-driving under different scenarios are discussed in this section. The scenarios with respect to a variety traffic conditions on roads are categorized as following:

(a) Different traffic demand: This aims to determine the performances of eco-driving under various traffic conditions. The flow rates per lane tested here are: 400 vehicles per hour, 600 vehicles per hour and 800 vehicles per hour which separately means free flow, medium flow and high traffic demands.

(b) Increasing eco-driving penetration rate: A mixed driving style tends to generate different traffic flow than a uniform driving style, especially at intersections where stop-and-go occurs frequently. Besides, the eco-drivers may force the following non-eco cars to change their behaviors and vice versa. So it is important to test the impacts of different eco-drivers penetration. The tested penetration rates of eco-drivers include: 0%, 20%, 40%, 60%, 80% and 100%.

The average vehicle fuel consumption (FC) is selected as the measure of environmental performance and average travel time (TT) is selected as the measure of traffic performance. The simulation was executed with the calibrated traffic model. In each scenario, the layout and the signal timing for intersection kept unchanged. For each traffic demand, the eco-driving penetration varied from 0% to 100% (by a step of 20%) and each scenario was simulated 7 times with different random seeds using calibrated simulation model in 3600 seconds simulation time. Therefore, a total of 126 simulations were performed. The total number of vehicles which have entered the network and every second acceleration and speed data were exported from the platform to calculate the fuel consumption in MATLAB. The results of 0% eco-driving penetration which also means normal driving are defined as the benchmark here. The results are presented in TABLE V :

TABLE V. RESULTS OF SIMULATION UNDER DIFFERENT SCENARIOS FOR NORMAL DRIVING AND ECO-DRIVING

Traffic Demand (pcu/lane/h)		Penetration of Eco-driving					
		0%	20%	40%	60%	80%	100%
400	FC (l/pcu)	0.00957	0.00963	0.00960	0.00960	0.00960	0.00961
	% Variation	-	0.65%	0.30%	0.30%	0.30%	0.45%
	TT (s/pcu)	0.01524	0.01537	0.01546	0.01554	0.01560	0.01571
	% Variation	-	0.86%	1.42%	1.94%	2.37%	3.08%
600	FC(l/pcu)	0.01076	0.0108	0.01070	0.01071	0.01070	0.01066
	% Variation	-	0.40%	-0.53%	-0.40%	-0.53%	-0.93%
	TT(s/pcu)	0.01716	0.01732	0.01730	0.01736	0.01740	0.01731
	% Variation	-	0.94%	0.80%	1.15%	1.43%	0.85%
800	FC(l/pcu)	0.01459	0.01431	0.01424	0.01411	0.01414	0.01377
	% Variation	-	-1.86%	-2.35%	-3.23%	-3.04%	-5.58%
	TT(s/pcu)	0.03194	0.03062	0.03076	0.02965	0.02962	0.02823
	% Variation	-	-4.12%	-3.68%	-7.14%	-7.25%	-11.6%

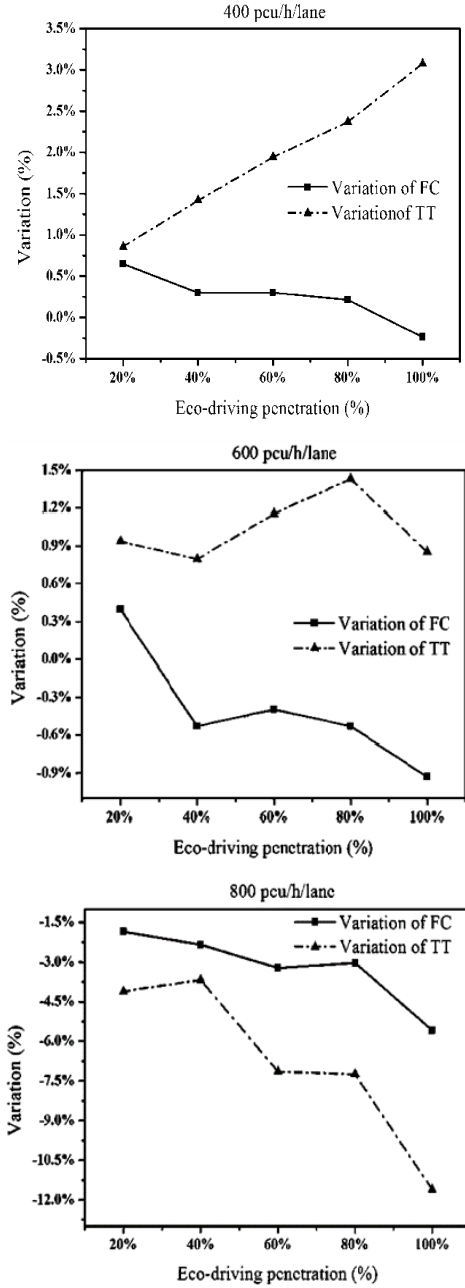## A. Impacts of Different Eco-driving Penetration

FIGURE II. IMPACTS OF DIFFERENT ECO-DRIVING PENETRATION

It can be seen from the Figure 2, with the increase of eco-driving penetration, the beneficial impacts of eco-driving behavior is becoming more obvious. However, the benefits are strongly affected by different traffic demands. When traffic demand is low (e.g. 400pcu/lane/h), the fuel consumption of eco-driving has a slight increase when the eco-driving penetration is about 20%. With the continuing increase of eco-driving penetration, the improvement of fuel consumption reduction is still not significant. On the other hand, the travel time keeps increasing with the eco-driving penetration.

When traffic demand is high (e.g. 800pcu/lane/h), the reduction of both fuel consumption and travel time is significant. When the eco-driving penetration is 100%, the reductions of fuel consumption and travel time reach maximum which are 5.58% and 11.6% respectively.

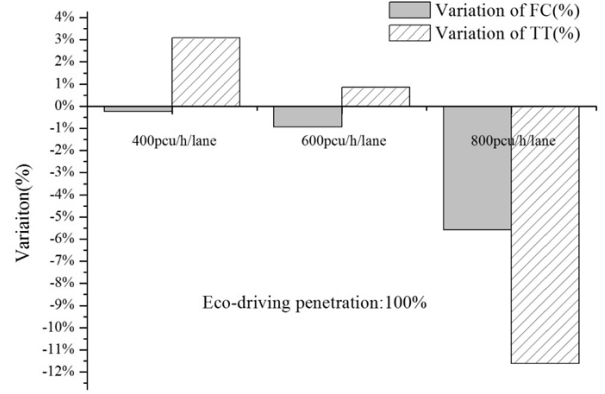## B. Impacts of Different Traffic Demands

FIGURE III. IMPACTS OF DIFFERENT TRAFFIC DEMANDS

From Figure 3, with the increase of traffic demand, the benefits of eco-driving become more and more significant. Both the fuel consumption and travel time of eco-driving have a considerable reduction compared to normal driving. However, when traffic demand is low, the effect of eco-driving is not very beneficial.

V. CONCLUSIONS

This study develops a microscopic simulation model to analyze the impacts of eco-driving behaviors on a single urban intersection. First, a field experiment with one diesel vehicle was conducted and the driving data both for normal driving and eco-driving was collected. The pre-analysis of collected data shows that the experiment has a good agreement with eco-driving rules. Then, the VISSIM simulation platform by integrating the VISSIM microscopic simulation model and fuel consumption model based on VSP was built. Finally, the impacts of eco-driving behavior under different traffic scenarios were evaluated. The main conclusions are as follows:

(a) Traffic demand has a great influence on the performance of eco-driving. When traffic demand is low, there are no significant benefits of eco-driving. When traffic demand is high, the benefits of eco-driving are much more obvious with great reduction both of fuel consumption and travel time.

(b) Eco-driving penetration is also a great influence factor for the eco-driving performance. When eco-driving penetration is low (about 20% in this study), eco-driving tends to bring negative impacts to the intersection. When eco-driving penetration continues increasing, the negative impacts gradually change to the positive impacts. The optimum is 100% with the most fuel consumption reduction in all the three scenarios.

However, this study still has some limits and must be considered in the analysis of results. Though the eco-driving

behaviors are properly calibrated in the microscopic simulation model, the model does not reflect the internal mechanism of eco-driving. Because the simulation model was built with the field test data, the simulation results can only represent the situation where the traffic conditions are mostly the same as the experiment. It may not be very convincing for other traffic situations and vehicle types. Further study needs to be done to build more accurate simulation model which can replicate detailed driving operations.

REFERENCES

[1] EEA 2014, Annual European Union greenhouse gas inventory 1990–2012 and inventory report 2014, European Environment Agency.

[2] The golden rules of ecodriving. Available: http://ecodrive.org /en/what _is _ecodriving-/the_golden_rules_of_ecodriving/ [2014, October, 22].

[3] Symmons, M., Rose, G. & Van Doorn, G. 2009, "Ecodrive as a road safety tool for Australian conditions", ROAD SAFETY GRANT REPORT, , no. 2009-004.

[4] Ho, S., Wong, Y. & Chang, V.W. 2015, "What can eco-driving do for sustainable road transport? Perspectives from a city (Singapore) eco-driving programme", Sustainable Cities and Society, vol. 14, pp. 82-88.

[5] Qian, G. & Chung, E. 2011, "Evaluating effects of eco-driving at traffic intersections based on traffic micro-simulation", Proceedings of the 34th Australasian Transport Research Forum, Adelaide, Australia, , pp. 1-11.

[6] Kobayashi I, Tsubota Y, Kawashima H. Eco-driving simulation: evaluation of eco-driving within a network using traffic simulation, urban transport XIII. WIT press; 2007.

[7] Ericsson, E. 2001, "Independent driving pattern factors and their influence on fuel-use and exhaust emission factors", Transportation Research Part D: Transport and Environment, vol. 6, no. 5, pp. 325-345.

[8] Mahmod, M., van Arem, B., Pueboobpaphan, R. & de Lange, R. 2013, "Reducing local traffic emissions at urban intersection using ITS countermeasures", IET Intelligent Transport Systems, vol. 7, no. 1, pp. 78-86.

[9] Jie, L., Van Zuylen, H., Chen, Y., Viti, F. & Wilmink, I. 2013, "Calibration of a microscopic simulation model for emission calculation", Transportation Research Part C: Emerging Technologies, vol. 31, pp. 172-184.

[10] Jie, L., Fangfang, Z., Van Zuylen, H. & Shoufeng, L. 2011, "Calibration of a micro simulation program for a Chinese city", Procedia-Social and Behavioral Sciences, vol. 20, pp. 263-272.

[11] Asamer, J., van Zuylen, H.J. & Heilmann, B. 2013, "Calibrating car-following parameters for snowy road conditions in the microscopic traffic simulator VISSIM",Intelligent Transport Systems, IET, vol. 7, no. 1, pp. 114-121.

[12] Treiber, M. & Kesting, A. 2013, "Microscopic Calibration and Validation of Car-Following Models–A Systematic Approach", Procedia-Social and Behavioral Sciences, vol. 80, pp. 922-939.

[13] Jiménez-Palacios, J. L. (1999). Understanding and quantifying motor vehicle emissions with vehicle specific power and TILDS remote sensing. PhD thesis, MIT, Cambridge, MA.

[14] Orfila, O., Saint Pierre, G. & Andrieu, C. 2012, "Gear Shifting Behavior Model for Ecodriving Simulations Based on Experimental Data", Procedia-Social and Behavioral Sciences, vol. 54, pp. 341-348.

[15] Hiraoka, T., Terakado, Y., Matsumoto, S. & Yamabe, S. 2009, "Quantitative evaluation of eco-driving on fuel consumption based on driving simulator experiments",Proceedings of 16th World Congress on Intelligent Transport Systems.