Experimental Analysis of Driving Behavior and Fuel Economy for Passenger Cars in Tokyo*

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1. Introduction

Awareness of the environment and the need for sustainable development is a growing concern in both developed and developing especially in the area of motorization. Road transport has become a major source of CO_2 emission that creates adverse effect on the surrounding environment alongside the issues on noise, congestion, local air pollution, and road accidents. While policymakers are pushing for more fuel-efficient vehicles, use of alternative fuels and efficient traffic operational strategies, drivers on the other hand can greatly reduce these impacts by driving more efficiently. This can be done by economical driving style or what we will introduce in concept as Ecodriving.

Ecodrive or Ecodriving (2,3,9) is primarily a driving technique designed to improve fuel economy, reduce CO_2 and mitigate the adverse impacts of road transport on its surrounding environment. It is the attitude of driving in an environmentally-conscious and energy-saving manner. In general, Ecodriving programs are directed to change a driver's driving behavior (1) through a generally improved driving operations and practical driving advisory. The basic operational technique (1) characterizing ecodriving includes: efficient speed application (starting, acceleration, and constant), switching-off the engine (e.g., during signal stop, parking etc.), appropriate choice of gear (manual transmission), appropriate control on acceleration and deceleration, and efficient coasting or gliding, anticipation of traffic condition. Alongside this, practical advisories were also recommended which includes: regular vehicle maintenance (e.g. engine, tyres, air con, etc.), minimizing mass and improving aerodynamics, anticipating traffic flow and signals, avoiding sudden starts and stops, driving at or safely below the speed limit, maintaining an even driving pace, appropriate choice of fuel type (i.e. octane level) and engine oil, wise usage of in-vehicle electronics (i.e., stereo, air con, etc.), and employment of on-board computers and navigational systems (e.g., cruise control, GPS, trip computers, rev counter, etc.). Ecodriving benefit is not only limited to lower emissions of CO_2 (11) and potential cost-savings on fuel (7). Research studies (2) also revealed that Ecodriving benefits further includes: narrowing the gap between real world and test/drive cycle estimates of fuel consumption and emission, reduction of local air pollutants, reduction of noise, enhanced traffic safety, reduced drivers stress (from speeding and overtaking), improved driving comfort, positive effects on vehicle wear and tear or maintenance (e.g. brakes, tyres), reduced costs (fuel, safety, repair and maintenance), improved service (increase in timely delivery) and improved trip time.

In real-world application, on-road fuel consumption and emission values are influenced by driving patterns which are in turn directly influenced by external factors such as: traffic characteristics, road characteristics, vehicle characteristics, driving characteristics, travel characteristics and other possible variables. To capture all this factors will require intensive investigation of its outcome influence on Ecodriving. Thus, this paper limits itself to investigate the outcome of ecodriving technique based on road, vehicle, driver, and trip characteristic. The objective of this study will then be to investigate the effect of Ecodriving by monitoring its resulting fuel consumption estimates before and after Ecodrive training. Specifically, to evaluate the factors that influence fuel economy.

2. Related Literature

History. Ecodriving started as economical driving style which originally started in Finland (8) in 1998. Economical driving was then translated and adopted in Sweden by the National Association of Swedish Driving Schools (STR), the Swedish National Road Administration (SNRA) and the Swedish National Energy Administration. And in 1999, some one hundred driving school teachers were trained as instructors of Ecodriving. Recent Ecodrive promotions are presented in Table 1 as Ecodrive campaign by country programs and initiatives. Note that, pilot Ecodrive initiatives in developing country application are in asterisk (*).

Fuel consumption and fuel-savings. In 1993, the office of Swiss Federal Energy initiated Eco-Drive courses. Results from the course program revealed that participants saved an average of 11.7% fuel (4). European Ecodrive programs, widely recognized that fuel consumption reduction effect about 10%-20% by driving operation (6). Following after the European programs on smart driving, the Energy Conservation Center of Japan (ECCJ) started the Ecodriving

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promotion that focus on effective and efficient driving execution. In 2002, ECCJ initiated a national driving field test or actual ride of “idling-stop” cars to investigate the effects of ‘smart driving’ resulted to a total average energy savings of 5.8% (rural=3.4% and urban=13.4%). Ukita (2003) and Katayama (2005) studies on the other hand, revealed 15%-20% fuel savings while Taniguchi (2005) revealed revealed 25%. Ecodriving methodology (6) reported potential fuel savings after training of drivers that drives the same vehicle. In the case of different transmission type, such as, European cars which are generally manual transmission type and Japanese cars which are most likely automatic transmission types, ecodriving technique demonstrated significant fuel savings and emission reduction (7).

Table 1 Ecodrive Programs and Initiatives by Country

COUNTRY	PROGRAM/ INITIATIVE
Argentina*	Deutsche Gessellsschaft Fur Technische Zusammenarbeit (GTZ) and the Argentinian Government selected courses: Buenos Aires area, 1999 and Mendoza area, 2003
Chile*	GTZ: Pilot Initiative in Santiago de Chile Area
Costa Rica*	GTZ: Pilot Initiative in San Jose Area
Indonesia*	GTZ: Jakarta and Subaraya Area
France	Regional Campaign RATP
Japan	Ecodrive 10 / Idling Stop Study on Buses at Cape Soya Hokkaido and Cape Sata, Kagoshima Prefecture / Smart Eco-drive Contest in Tokyo, October 2004
Austria	Spritspar-Initiative / NIGG Bus Company, 2000
Netherlands	Het Nieuwe Rijden / Car Panel Consumentenbond, 2002 / Logistics Companies, 1995-2003
Greece	Centre for Renewable Energy Sources of Greece, Organization of Urban Transportation in Athens, and the Thermo-bus company, 2008
Switzerland	Eco-driving Quality Alliance / Swissenergy: Eco-Drive® Under Test Evaluation of Eco-Drive® Courses, by the Swiss Federal Office for Energy in 2000 / Canon Company
Finland	Motiva :Ecodriving Network, 2008
Scotland	Top Four Tips and Best of the Rest
Poland	Ecodrive Europe
United Kingdom	Smarter Driving (“Act on CO_2 ” Campaign) / Drivers Standards Agency, 2004
United States	USA Ecodrive
Germany	Hamburger Wasserwerke (HW), 2003 / Frankfurt Motor Show, 2007
Spain	Real Catalonia Automobile Club (RACC), October 2003
Belgium	Eco-driving, National Campaign / Bond Beter Leefmilieu (BBL) Campagnes and Tire Profile Centre, September 2008
Sweden	Energy 2000
Czech Republic	A- Class Driver, Golden Rules of Ecodriving

Driving operation. Driving operations during a trip significantly influence the resulting fuel consumption and emission values. In the SFE training course (4) resulting driving operation revealed that: participants in the Eco-Drive course drive more smoothly than non-participants, gear-changes along the test route averages by one-fifth lower than the figure measured on non-participants, 83% of the participants “always” engage in the highest possible gear when driving their cars and 93% maintain an anticipatory driving style to avoid unnecessary braking and acceleration. On the other hand, the driving operation study of Taniguchi and Miyasaka (9) revealed that strategic reduction of fuel consumption requires curbing of three specific operation aspects: the starting acceleration, idling-stops and vehicle speed. Such that for trips generated in urban area appropriate control of the starting acceleration and idling-stops is necessary. While in suburban area application appropriate driving operation should focus on controlling the fluctuation of vehicles' speeds. Another study by Taniguchi et al., (10) validates that during driving operation significant fuel is consumed at the moment the vehicle begins or starts to accelerate. Recommendations of the study suggest that initially starting with fairly weak acceleration will result to lower fuel consumption. Thus, it is recommendable to follow the conscious "Speed of 20km/h with 5 seconds after starting" rule to improve on fuel economy.

3. Methodology

The basic requirement of the study includes driver, vehicle and equipment alongside three sets of data collected thru different stages of data gathering. Fifteen candidate drivers and vehicles equipped with on-board data-logging equipment were considered in this study.

Invitation letters for interested drivers to join the research and survey were distributed in the university parking lot of Tokyo Institute of Technology. Referrals from networks of friends and colleagues were also communicated with the same invitation thru emails. Candidate drivers with vehicles compatible to instrumentation for the study were chosen for the study. Drivers profile and driving characteristics were evaluated thru administered questionnaires in the study. For vehicle, Japanese cars from model 2000-2009 and vehicle specification requirement compatible with the monitoring equipment is a prerequisite of this study. The instrumented vehicles with GPS and Fuelmeter equipment were used to monitor drivers driving operation, movement and location. Global Positioning System (GPS) equipment from the office of the Integrated Behavioral Science (IBS) was employed to monitor the movement and location of the tested vehicles. Instantaneous values of location: latitude, longitude and altitude per 0.10second were collected from driver’s trip data. The data are then processed, cleaned, filtered and logged in a database. After which, the data are then analyzed. Fuelmeter equipment from the Energy Conservation Center of Japan (ECCJ) was also employed to monitor driving operation. The equipment is connected or attached thru the car’s On-Board Diagnostic (OBD) ports. Vehicle with compatible OBD-II are prerequisite of the Fuelmeter for collecting instantaneous data parameters per 0.10second. These parameters include velocity, distance, fuel consumption, engine velocity and acceleration. The lumped and

logged database from Fuelmeter readings are then serves as parameters for statistical analysis and street network evaluation and as attributes for mapping purposes. Route in the study are defined as fixed rote and random routes. A fixed route was defined for driving test of the candidate drivers during the training day. Before (3days) and after (3days) evaluation of drivers trips in real-time and on-road driving are defined as random routes.

Prior to actual data collection an initial pre-testing evaluation for compatibility of monitoring instruments and vehicle were necessary. This involves vehicle-instrument calibration. As the vehicle pass the initial prequalification, drivers were then subject to an initial driving test to check if the data logging of GPS and Fuelmeter equipment are working properly. Drivers owning the vehicles that pass the calibration test become candidates of the study.

After vehicle and equipment calibration, the next stage is data collection. Data collection is divided into three separate stages, namely: the data collection from driver's trips, the data collection from driver's questionnaires and the data collection from Ecodrive training of drivers. The collections of the dataset are then summarized as follows: Drivers Trip Data, Ecodrive Training Data and Driver's Questionnaire Data. First on Driver's Trip data. To test the effect of Ecodrive training, a pretest-posttest study with intervention or treatment was used. In this case the intervention is the Ecodriving training program while two sets of driver's trip data were collected for three days each. The first round of this data collection is the pretest or normal driving dataset which are collected prior to the ecodrive training day. After the Ecodrive training day, for the second round, drivers are again subjected to a three-day data collection which serves as the posttest Ecodriving dataset. Second, on Ecodrive Training data. Ecodrive training of drivers were handled by the office Energy Conservation Center of Japan (ECCJ). During the Ecodrive training day, drivers undergo driving orientation, Ecodrive introduction, driving test and driving evaluation. The short orientation session introduces normal driving operations of drivers and its corresponding effect on fuel consumption values. Ecodrive is then introduced alongside driving operation techniques. After which, the participant are subjected to a driving test - in their normal driving and Ecodrive condition. Evaluation, consultation and driving advisory of each driver ensue thereafter. Lastly, on Driver's Questionnaire data. To test the effect of Ecodrive training on drivers driving behavior, a pretest-posttest questionnaire was also given to the driver. The questionnaires include information on drivers' profile, trip and driving characteristics and driving perceptions. The pretest questionnaires were administered before the Ecodrive training while the posttest questionnaires were administered on the last day of the trip data collection.

4. Results and Analysis

This section presents the results drawn from the Ecodrive Training dataset. The data were drawn from pretest (before) and posttest (after) evaluation of Ecodrive training and the subsequent driving test around Tokyo, Hachoobori area .

Drivers Profile. Fifteen candidate drivers comprising three females and twelve males joined the Ecodrive program from March to May 2010. By profile, 41% of the candidates are under 30yrs of age comprising students and young professionals while the remaining candidates are between the ages of 30-70 comprising non-professionals and professionals. By driving experience 59% have less than 20yrs of driving experience. Most candidates have a household size of 3-4members and 71% of them own their cars (59% drives without passengers). Also, in terms of car usage, most candidates (53%) drive on daily basis while the remaining candidates drive their car only a couple of times in a week. Trip purposes are usually: to go to work (33%) or school (24%) and shopping (24%) or leisure (14%). Most used car accessories are the air-conditioning and video watching. Generally, the cars are newer models (2000-present), automatic transmission type (82%) and gasoline fueled. Model brands of candidate's car ranges between: Toyota (44%), Nissan (31%), Honda (13%), Subaru (6%), and Mazda (6%). And, on regular basis, candidates have their car checked for maintenance every six-month period.

Table 2 Descriptive Statistics of Vehicle Parameters

T- Test for Dependent Samples p <. 001	*Mean*	*Std.Dv.*	*N*	*t*	*df*	*p*
Fuel Economy (km/l)- Pretest	9.320	0.840	15.000			
Fuel Economy (Km/l)- Posttest	10.570	0.630	15.000	5.456	14.000	0.000
Specific Fuel Consumption (cc/sec)- Pretest	0.182	0.019	15.000			
Specific Fuel Consumption (cc/sec)- Posttest	0.103	0.030	15.000	17.238	14.000	0.000
Travel Distance (km)- Pretest	2.700	0.017	15.000			
Travel Distance (km)- Posttest	2.698	0.021	15.000	0.315	14.000	0.757
Travel Time (sec)- Pretest	654.000	91.474	15.000			
Travel Time (sec) -Posttest	693.600	62.787	15.000	-1.653	14.000	0.120

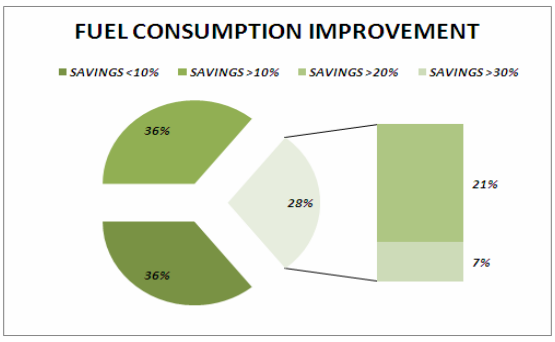

Figure 1 Fuel Consumption Improvements

Fuel Economy. A paired t-test was performed to compare the fuel economy before (i.e. normal driving) and after (i.e., Ecodriving) the intervention between test is the training drivers with Ecodrive. Results revealed that there is a significant difference in the means of fuel economy (Table 2) before (M=9.32) and after (M= 10.57) the training condition; t(15)= 5.456, p=0.001. Similar results are revealed in specific fuel consumption values. These suggest that after training the drivers with Ecodrive their fuel economy value increased. In terms of fuel consumption improvement, almost all of the candidates had an overall improved values as shown in the distribution in Fig. 1. One driver though had a personal adjustment issue in applying Ecodrive with a Hybrid car. Results of fuel savings indicate that among candidates, 72% (10 drivers) had savings within 20% value while 28% (4 male-drivers) had achieved fuel savings above 20% and 30% range. The latter maybe attributed to age and driving experience since three of them are from older age (>40yrs) bracket with longer experience (license age >20yrs) in driving.

TripTime and Distance. The tested route during the Ecodrive training has a total length of about 2.7km. Results in Table 2 revealed that the Ecodrive bears no significant difference or effect ($p < .001$) on the mean values of trip distance before and after drivers training indicating that the same travel distance was covered by the drivers. With respect to time, it reveals no significant effect although the negative value of the T-test indicates an increase in the values of time after the Ecodrive training. The data in this case showed that among drivers, 73% increased their travel time after Ecodrive training. This increase of time among drivers can be attributed to Ecodrive guideline on slow starting acceleration (i.e. initial start at 20kph within the first 5secs), the application of gentle driving along the entire trip and the advice to slow down (60kph to 40kph within 200m range) as car approaches a traffic signal.

Stops. As vehicle travels along a given route, stops between traffic signals are expected. In this study, T-test results revealed that there are no significant differences in the time of stops ($t=0.026$, $p<0.001$) and the number (i.e. count) of stops ($t=-1.835$, $p<0.001$) before and after Ecodrive training. However, there is slight increase in the number of stops after Ecodrive training as indicated in the negative value of the T-test. Overall, we can conclude that there is no significant effect of Ecodrive with stops.

5. Conclusions

Preliminary assessment of the driver pretest and posttest data was initiated to achieve the objective of this paper. The study has successfully demonstrated that Ecodrive technique increase the fuel economy of drivers. The resulting fuel economy improvement from normal driving to Ecodriving among fifteen candidates revealed this conclusion. In addition to fuel economy improvement, this study also revealed that adopting Ecodrive do not significantly increase travel time and stops.

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References

1. Af Wahlberg, A.,2007,Long-Term Effects Of Training In Economical Driving: Fuel Consumption, Accidents, Driver Acceleration Behavior And Technical Feedback, International Journal of Industrial Ergonomics,ISSN 0169-8141, Vol. 37, No. 4, Pp. 333-343.
2. Commission Internationale des Examens de Conduite Automobile (CIECA), Internal Project on “Eco-Driving” in Category B Driver Training & Driving Test, Eco-driving Project Final Report, May 2007. http://www.ecodrive.org/fileadmin/dam/ecodrive/Downloads/CIECA_Eco-driving_project_final_report_EN.pdf
3. Deutsche Gessellsschaft Fur Technische Zusammenarbeit (GTZ), Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities Module 4f: Ecodriving. http://www2.gtz.de/dokumente/bib/05-0524.pdf
4. Hornung,D., Stiefel, A., Stampfli,M., von Hebenstreit, B., 2000, Evaluation of the Eco-Drive Courses, in Response to a Commission from the Federal Office of Energy (German), Bern 2000 (BBL No. 905.527 d).
5. Katayama,H.,Taniguchi M.,2005,A Study On Practical Training System For Energy Conservational Drives, Proceedings of the Society of Automotive Engineers of Japan (JSAE),Vol. 80-05, Pp. 20.
6. Morimitsu,N.,Taniguchi,M.,Sambuichi, H.,2005,Eco-Drive Promotion Activities In Europe, Proceedings of the Society of Automotive Engineers of Japan (JSAE), Vol. 80-05, Pp. 9-12.
7. Miyasaka,T.,Taniguchi,M.,Sambuichi, H., 2005, Potentiality of Effects by Fuel Conservation Driving in Automatic Transmission Car, Proceedings of the Society of Automotive Engineers of Japan(JSAE), Vol.80-05 Pp. 13-16.
8. Swedish National Road Administration, Impact of EcoDriving on Emissions and Fuel Consumption http://publikationswebbutik.vv.se/upload/2000/1999_165E_impact_of_ecodriving_on_emissions_and_fuel_consumption.pdf
9. Taniguchi M., Miyasaka T.,2005, A Study on Practical Energy Saving Drives under Traffic Condition, Proceedings of the Society of Automotive Engineers of Japan (JSAE), Vol. .80-05, Pp. 21-24.
10. Taniguchi, M., Kasai, J., Sambuichi, H., 2006, A Study on the Fuel Consumption for Driving at Vehicle Starting Under Energy Saving Drives, Proceedings of the Society of Automotive Engineers of Japan (JSAE), Vol.26-06.
11. Ukita M., Shirota H., 2003, Study on The Effect of Eco-Driving by Equipping with Fuel Consumption Meter, Proceedings of Annual Meeting of Environmental Systems Research, Vol. 31, Pp. 413-419.