Relationships between Driving Style and Fuel Consumption in Highway Driving

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ABSTRACT

This paper aims to investigate the relationship between driving style and fuel consumption through on-road assessment in highway driving. In order to find prominent measures in driving style which affect the fuel consumption, 15 younger drivers were asked to drive approximately 36Km of highway, and driving data, including real-time fuel consumption, vehicle speed, gear selection, brake/acceleration pedal usage and steering angle, were collected.

The correlation analysis results suggested that the fuel efficiency was significantly affected by the average depth of acceleration pedal in highway driving in which the highest gear was engaged. Another interesting finding in this analysis was that the fuel consumption can be estimated by observing the variations in steering wheel because the standard deviation of steering wheel angle and the fuel consumption were highly correlated.

INTRODUCTION

High oil prices and a treaty on global climate change are driving motor vehicle manufacturers and suppliers to improve vehicle fuel efficiency through sophisticated and expensive systems and components. However, if the most efficient vehicle would be used by an aggressive driver, it would have poor efficiency[1][2]. Although it is known that driving style strongly affect the fuel efficiency, existing empirical knowledge about the relationship between driving style and fuel efficiency was limited[3]. Furthermore, driving style is also influenced by other variables such as the driver parameters, road environment parameters, and vehicle parameters[4][5].

Eco-driving coaching and Eco-driving assistant is one of the easiest ways for reducing the Green-House gases and improved the fuel consumption with a relatively low cost[6]. Because improved driving behavior is the most effective method in terms of cost-benefit ratio[7].

Driving behavior can be determined by measuring such as selection of appropriate gear, using style of acceleration pedal, brake pedal and engine Fuel Cut-off mode.

In order to understand the relationship between fuel consumption and driving style, on-road experiments were conducted with 15 subjects who drove approximately 36Km of highway. The collected data was used to assess driving style and fuel efficiency, and to develop Eco-Drive guidelines from the driving style based fuel consumption model.

In this study, we found that the standard deviation of steering wheel angle can be a prominent driving style measure for estimating fuel consumption on highway driving. The results from this study demonstrated that the steering wheel angle is more highly correlated with fuel consumption than pedal usage measures such as time of accelerator pedal usage and deep of accelerator pedal usage.

DATA COLLECTION METHOD

In order to assess the relationships between driving style and fuel consumption, an instrumented vehicle which can capture all driving events such as driving style, vehicle status and road environment was developed.

SUBJECTS

Subjects were required to meet the following criteria: age between 25-35, drive on average more than twice a week, be in self-reported good health and free from major medical conditions, not take medications for psychiatric disorders and have not previously participated in a driving study. The sample consisted of 15 in the 25-35 age range (M=28.8, SD=3.6).

EXPERIMENT EQUIPMENT

The study was conducted in a full size sedan (engine size : 3 .3 liters) which is instrumented for time synchronized data collection from embedded sensors including the vehicle's controller area network (CAN) bus

and cameras for capturing driver behavior and vehicle surroundings.

Figure 1 shows that the instrumented vehicle platform consists of six video cameras (two for driver and four for road environment monitoring), high speed and low speed CAN logger, driver gaze tracking system, global position system (GPS), real-time fuel consumption measuring system, vehicle gradient measuring system, image processing system for detecting lane position and angle, and physiological signal sensing system.

It runs through four PCs which are Main Control PC, Sub Control PC, Driver Gaze Tracking PC, and Physiological Signal PC. Each PC has signal acquisition module from sensor systems and real-time visualization module. They are independent, work separately to give specific information about driver's behavior, and store synchronizing data with master time.

PROCEDURE

Experimental procedures were structured around the driving test.

The first stage of the experiment, the availability of safe driving (Safety Protocol) and describe the identification and signature (Consent & Overview) was composed.

Driving experiment were tested a highway driving after practice driving. Subjects should practice driving of about 20 minutes. The highway driving experiment begins when subject has used to driving a experiment car.

EXPERIMENTAL ENVIRONMENT

In order to collect highway driving data, 36Km-highway (20 minutes) path was selected as shown in Figure 2. The driving road has speed limit of 100 kph, two lanes in each way, and about 8Km of uphill and downhill (3~5 percent slope)

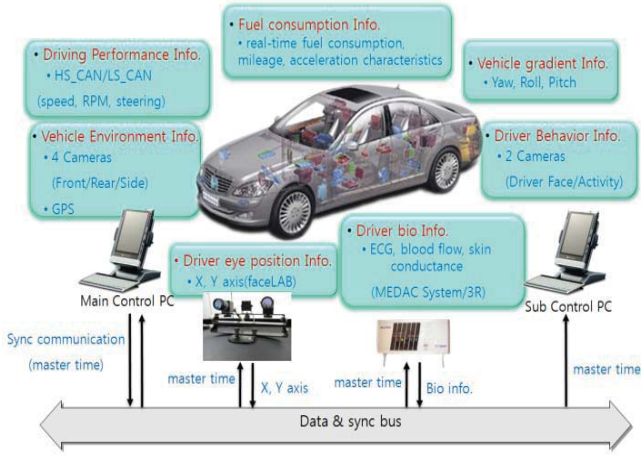

Figure 1. Real-time Driver-Vehicle-Environment Monitoring Platform

The driving experiments were conducted at 11:00 to 11:30 a.m. and 3:30 to 4:00 p.m., to avoid peak hours and maintain relatively low traffic density, and consequently subject can drive the car as their own driving style.

All the experiments were conducted on dry road surfaces for driving safety.

RESULTS

CORRELATION ANALYSIS

Table 1 shows that correlation between driving style variables and fuel consumption in highway driving. Previous studies suggested that fuel consumption and the driving style variables such as a accelerator pedal usage and average gear level (Gear_SelAvg) are statistically significant correlated. The most significantly correlated variable was an average depth of the acceleration pedal (PsAcAvgDep) ($p<0.01$).

Meanwhile, this study proposes a new driving style variable from a steering wheel measure, that is, the standard deviation of steering wheel angle (SWL_AngStd). As shown in Table 1, the standard deviation of steering wheel angle shows the highest correlation coefficient among driving style variables ($p<0.01$).

The correlation analysis results suggested that the fuel efficiency was significantly affected by the average depth of acceleration pedal in highway driving in which the highest gear was engaged.

Another interesting finding in this analysis was that the fuel consumption can be estimated by observing the variations in steering wheel because the standard deviation of steering wheel angle and the fuel consumption were highly correlated.

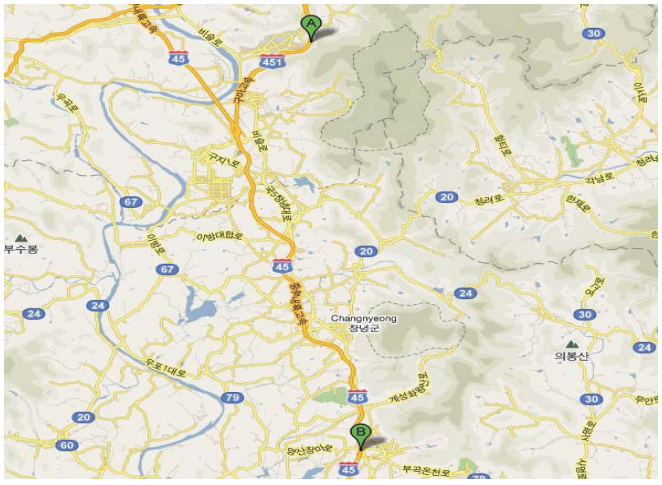

Figure 2. Experimental Environment

Table 1. Pearson Correlations

	Accelerator Pedal							Gear	
	PsAc Count	PsAc AvgTime	PsAc StdTime	PsAc AvgDep	PsAc StdDep	RIA2A AvgTime	RIA2A StdTime	Gear_Sel Avg	Gear_Sel Std
Millage	**-.539***	**.710****	**.725****	**-.880****	**-.850****	**.753****	**.721****	**-.547***	.509
	Brake Pedal					Steering Wheel			
	PsBr Count	PsBr AvgTime	PsBr StdTime	RIB2B AvgTime	RIB2B StdTime	SWL_Vel Avg	SWL_Vel Std	SWL_ Ang	SWL_ Ang Std
Millage	-.337	-.214	-.467	-.264	-.125	-.347	-.497	.040	**-.932****

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

MULTIPLE REGRESSION ANALYSIS

Fuel consumption formula can predict the fuel consumption of highway driving. And driving behavior (gear selection, brake/acceleration pedal usage and steering wheel usage etc.) variables of fuel consumption formula may be presented in t he guidelines of proper driving behavior.

In order to predict the fuel consumption using driving style variables such as gear selection, brake/acceleration pedal usage, and steering wheel usage, fuel consumption model was suggested. With the knowledge of relationship between driving style and fuel consumption, the driving style guidelines for high fuel efficiency can be developed.

In this study, multiple regression analysis was adopted for modeling a fuel consumption formula using previous driving style variables (acceleration pedal usage) and new driving style variables (steering wheel angle).

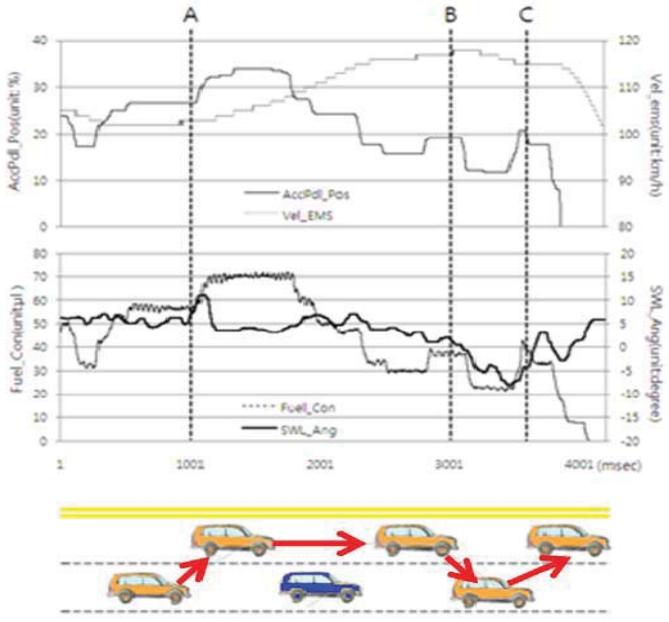

Figure 3. Passing the front car

First fuel consumption formula is as follows :

$$y = 17.70 + 0.1x_1 - 0.38x_2$$
(1)

In the first formula x_1 is average time of accelerator pedal usage interval (RIA2AAvgTime), x_2 is average deep of accelerator pedal usage (PsAcAvgDep).

Second fuel consumption formula is as follows :

$$y = 22.747 - 2.437x_1 + 0.152x_2$$
(2)

In the second formula x_1 is standard deviation of steering wheel angle (SWL_AngStd), x_2 is average time of accelerator pedal usage interval (RIA2AAvgTime).

Table 2 dis plays the actual fuel consumption (Km/l) of drive approximately 36Km of hig hway and fuel consumption using fuel consumption formula (1), (2).

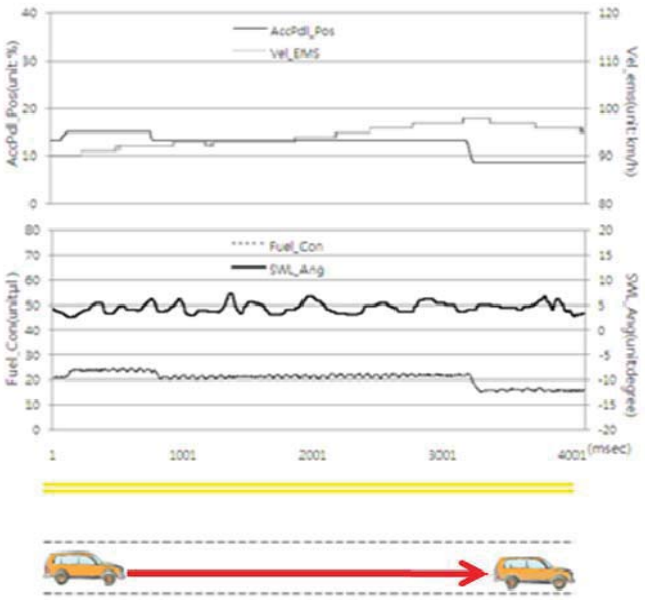

Figure 4. Follow the car in front

Comparing the accuracy of the fuel consumption formula, formula (2) using standard deviation of steering wheel angle (SWL_AngStd) and average time of accelerator pedal usage interval (RIA2AAvgTime) is more accurate

DISCUSSION

In this study, we performed the driving experiments for 15 participants of age 20~ 30. The driving road is highway of about 36km (about 20 minutes) and speed limit of 100kph, lane of two-way.

The results from this study suggest that the steering wheel angle is more accurately correlated with fuel consumption than pedal usage measures of previous studies. And the result suggested that it is necessary to make constant speed driving a way of life without passing cars in order to increase fuel efficiency.

The larger the standard deviation of steering wheel angle is that operation means that the handle is larger. This occurs when a passing the front car. Due to sudden acceleration when a passing the front car is to use a lot of fuel.

Figure 3, and Figure 4 show that passing the front car and follow the car in front when driving of highway.

Figure 3 shows that passing the front car that A is from two-lane road to one-lane road, B is from one-lane road to two-lane road, C is from two-lane road to one-lane road. A point was increased that steering wheel angle (SWL_Ang).

On the contrary, Figure 4 shows that follow the car in front when driving of highway. Figure 4 didn't show up as a Figure 3. As this result, sudden acceleration when passing the front car was increased that fuel consumption.

Therefore, in order to improve fuel economy at driving of highway is considered that without a passing the front car in constant driving.

Also, at this point fuel consumption (Fuel-Con) has increased.

Table 2. Accuracy of Fuel Consumption Formula

ID	Fuel Efficiency (km/l)	Fuel Consumption Formula No.1 (Accuracy, %)	Fuel Consumption Formula No.2 (Accuracy, %)
20m01	11.32	11.52 (98.20)	**11.34 (99.83)**
20m02	12.75	12.96 (98.33)	**12.68 (99.47)**
20m03	12.11	12.21 (99.20)	12.39 (97.68)
20m04	11.37	12.20 (92.73)	**11.32 (99.55)**
20m05	12.86	12.03 (98.67)	**12.69 (98.67)**
20m06	12.62	12.46 (98.69)	**12.67 (99.59)**
20m07	13.04	12.87 (98.64)	**13.06 (99.82)**
20m08	12.84	12.74 (99.22)	12.58 (97.97)
20m09	14.49	14.34 (98.97)	**14.49 (99.34)**
20m10	12.04	11.81 (98.08)	**12.05 (99.91)**
20m11	12.05	11.40 (94.61)	**12.00 (99.61)**
20m12	12.21	12.17 (99.64)	12.59 (96.85)
20m13	12.76	12.67 (99.30)	12.55 (98.34)
20m14	12.02	12.11 (99.26)	12.25 (98.12)
20m15	13.33	12.92 (96.95)	**13.05 (97.91)**

The cause is depth of the accelerator pedal (AccPdl_Pos). At this point, depth of the accelerator pedal is 25 ~ 30%. This trend has shown the same to B and C.

CONCLUSION

We examined whether a steering wheel angle is relevant to a comprehensive measure of driving behavior related to fuel consumption in highway driving. To do this, we compared and analysed steering wheel which is presented as a driving behavior measure related to fuel consumption in this paper and driving behavior measures of previous studies

Suggested in previous studies measuring variables associated with fuel consumption such as a accelerator pedal and average gear level (Gear_SelAvg) is a statistically significant correlation.

The largest correlation of measured variable is a average depth of the accelerator pedal used (PsAcAvgDep) of within the 99% level of significance.

Meanwhile, this study proposes a new measurement variables of the handle such as standard deviation of steering wheel angle (SWL_AngStd) is a statistically significant correlation. Especially, the steering wheel angle shown that correlation coefficient (within the 99% level of significance) higher than previous studies measuring variables.

The results from this study suggest that the steering wheel angle is more highly correlated with fuel consumption than driving behavior measures of previous studies. And they tell that it is necessary to make constant speed driving a way of life without passing cars in order to increase fuel efficiency.

ACKNOWLEDGMENTS

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Areas of interest : Assess driving style and fuel efficiency, Developing for Eco-Drive guidance system, Designing for older drivers, Driver’s workload assessment (On-Road & Simulator), Advanced Human-Vehicle Interface

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