# QUANTITATIVE EVALUATION OF ECO-DRIVING ON FUEL CONSUMPTION BASED ON DRIVING SIMULATOR EXPERIMENTS

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## ABSTRACT

Eco-driving has attracted a great deal of attention as a countermeasure against global warming to reduce emissions of carbon dioxide from vehicles. Fuel economy would be improved by the eco-driving behaviors such as a few changes in velocity, smooth acceleration at start, active use of engine brake, and so on. However, the fuel consumption reduction effects of the eco-driving have still not been verified adequately. Furthermore, there are few studies which verify effects of a fuel consumption meter and instruction contents of the eco-driving on the driving behaviors. In the present paper, driving simulator experiments are performed to evaluate the fuel consumption reduction effects of the presentation of the fuel consumption meter and the instructions of the eco-driving.

## KEYWORDS

3. ITS for drivers / C. Human Machine Interaction

## 1. INTRODUCTION

Many researchers have indicated that an eco-driving technique is effective to reduce fuel consumption, and therefore, it has been promoted with a slogan, ‘10 tips for fuel-conserving eco-driving’ in Japan [1]. As countermeasures to realize a low emission driving, it recommends not only direct instructions about driving such as a smooth acceleration but also overall reconsideration about the driving behavior such as an idle-stop, temperature setting of air-conditioner, and path planning. Recently, a lot of vehicles equip with a fuel-consumption meter, a device which provides a warning when a fuel efficiency of the vehicle becomes bad, and a device which turns on a lamp when the fuel efficiency becomes good.

In Germany, an eco-driving technique which differs a little bit from the Japanese eco-driving technique has been promoted. In this manuscript, the technique is called the German

eco-driving. The driving technique of which the driver accelerates his/her vehicle somewhat faster to the velocity range of good fuel efficiency (about 60 to 70 [km/h]) is the most different point from the Japanese eco-driving.

In this study, the subjects perform three types of following behavior on the driving simulator environment; 1) a normal driving, 2) a driving when the fuel consumption meter is presented, and 3) a driving after instructions for the Japanese eco-driving or the German eco-driving (subjects are divided into two groups only in this experimental condition). Based on the experimental results, the present paper evaluates the influences of the eco-driving instructions and the presentation of the fuel-consumption meter on the fuel economy.

## 2. ECO-DRIVING

### 2.1. Japanese eco-driving

Ten tips for fuel-conserving eco-driving [1] above mentioned recommend 10 types of driving behaviors; *1) accelerate gently, 2) keep your speed constant, 3) slow down by decelerating, 4) limit the use of your air conditioner, 5) do not idle your engine, 6) do not warm up your engine before starting off, 7) know your itinerary, 8) check your tire pressure regularly, 9) reduce your load, 10) respect parking regulations.* Items 1) – 3) represent methods to realize low-fuel consumption by changing the driver's running pattern, items 4) – 6), 8), and 9) show methods to realize low-fuel consumption without changing the running pattern, item 7) is a method to reduce fuel consumption itself by reducing the vehicle mileage, and item 10) is equivalent to a method to realize fuel-efficient traffic flow. The present paper evaluates the three types of driving behaviors with respect to items 1), 2), and 3).

### 2.2. German eco-driving

German eco-driving is based on the idea that the total fuel-efficiency will be improved when the vehicle is accelerated earlier to the velocity range of good fuel efficiency [2]. The following driving techniques of the German eco-driving are major different points from the Japanese eco-driving; *1) accelerate adequately (but, don't accelerate hardly), 2) use higher gear and keep your engine speed low, 3) release gas pedal and keep coasting in the velocity range of good fuel-efficiency.*

### 2.3. Previous studies about eco-driving

Matsumoto et al. [3] analyzed the effect of difference between the Japanese eco-driving and the German eco-driving on fuel consumption rate based on actual vehicle experiments. In the study, the estimated fuel consumption rate was calculated based on the distribution of velocity – acceleration in the three driving cases; normal driving, the Japanese eco-driving, and the German eco-driving. In other words, it did not discuss the difference based on the actual fuel consumption rate. Kato et al. [4] conducted the test-riding events of eco-driving to compare

the difference between the eco-driving with the consciousness of gentle acceleration (equivalent to the Japanese eco-driving) and the eco-driving with the consciousness of faster acceleration (equivalent to the German eco-driving). The experimental results reported that the fuel consumption rates of the Japanese and the German eco-driving were improved by +11.6 % and +7.1% respectively, compared to the normal driving.

## 3. MOTIVATION

### 3.1. Intrinsic motivation and extrinsic motivation

Driver's motivation is very important to continue the eco-driving behavior. There have been lots of studies about motivation in psychology, and one of the most famous classifications with respect to the motivation is intrinsic motivation and extrinsic motivation [5]. The extrinsic motivation depicts an incentive to do something that arises from factors outside the individual, such as rewards or punishments. It is highly possible that the behavior based only on the external rewards brings frustration and collapse because greater rewards are necessary to keep the behavior. In contrast, the intrinsic motivation is an incentive to do something that arises from factors within the individual, such as a need to feel useful or to seek self-actualization. That is, an intrinsic motivated person does not want any external rewards, because the behavior itself is end. When persons feel that they are capable and cause of their behavior is in them, they would make exertions with lots of motivation in order to seek more capability and a sense of self-determination.

### 3.2. Internalization of extrinsic motivation

The extrinsic motivation can be classified into four levels depending on the degree of internalization and self-determination [5]. *External regulation* is a typical case of extrinsic motivation. *Introjection* occurs when an individual takes in an external regulation, but does not accept it as one's own. This kind of regulation comes from within the individual, but is relatively externally controlled. *Identification* refers to an individual identifying with the value of a behavior. Hence, the individual feels that the cause of behavior comes from within. *Integration* is the highest level of internalized extrinsic motivation. In addition to identifying with the value of the behavior, it has been fully integrated with other aspects of the self. Therefore, the individual has a full sense that the behavior is part of who he/she is.

### 3.3. Motivation in Eco-Driving

As mentioned above, the human behavior would continue in the case where it arises from the intrinsic motivation and he/she can always acquire a sense of competence and self-determination or in the case where it arises from the extrinsic motivation and the value of the behavior is internalized to become integration level based on a sense of self-determination. The present study performs two types of experiments. In the first experiment, the fuel consumption meter is presented to subjects and they do not receive any instructions about

eco-driving. And, in the second experiment, the subjects receive instructions about eco-driving. If the driving behavior to improve the fuel consumption rate arises in the former condition, it implies that eco-driving behavior arises from intrinsic motivation.

## 4. OUTLINE OF DRIVING SIMULATOR EXPERIMENTS

### 4.1. Calculation of fuel consumption

A driving simulator used in the present paper calculates an instantaneous amount of fuel consumption [kg/s] based on a fuel consumption map (Fig.1), which is defined by an engine speed and a gas pedal input. Instantaneous fuel economy [km/l] is also computed based on the instantaneous amount of fuel consumption, density of gasoline, and the vehicle velocity. Figure 2 illustrates a meter display of the driving simulator, which consists of a speedometer, a fuel consumption meter, and a warning lamp for the headway distance. The fuel consumption meter presents the instantaneous fuel economy and the average fuel economy.

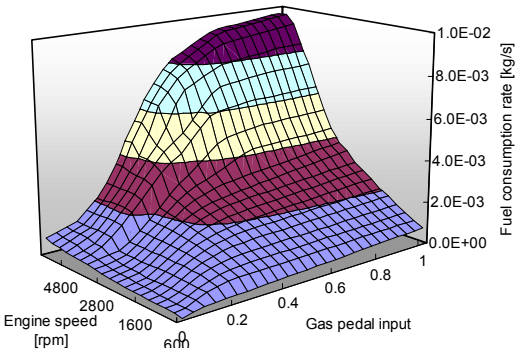



Fig.1 Fuel consumption

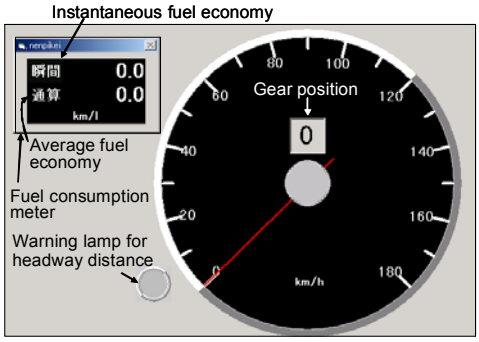



Fig.2 Meter display

### 4.2. Experimental condition

The subjects were 12 males in their twenties (average age: 23.8 years). As shown in Fig.3, the subjects drove a virtual vehicle to follow a preceding vehicle along the experimental course consisting of a two-lane road, the length and width of which are approximately 9 [km] and 7 [m], respectively. The subject's vehicle equips with a 5-speed automatic transmission and the vehicle weight is 1.7 [t]. However, it does not have functions of automatic idle stop and fuel cut, and the subjects cannot change the gear position manually. The preceding vehicle moves according to the velocity pattern of JC-08 mode as shown in Fig. 4. The experimenter gave the subjects instructions to follow the preceding vehicle with an appropriate headway distance. After a practice driving, the subjects drove their vehicle under three driving conditions; 1) a normal driving without the fuel consumption meter (*Normal driving condition*), 2) a driving when the fuel consumption meter is presented (*FC-meter condition*), and 3) a driving without the fuel consumption meter after instructions for Japanese or German eco-driving (*J-Eco drive condition* or *G-Eco drive condition*). Subjects #1 – #6 received the Japanese eco-driving instructions, and Subjects #7 – #12 received the German eco-driving instructions.

Fig.3 Front view of driving simulator

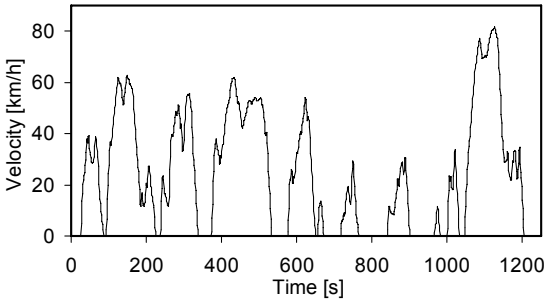



Fig.4 Velocity pattern of JC-08 mode

## 5. EXPERIMENTAL RESULTS AND DISCUSSIONS

### 5.1. Average fuel economy

Table 1 shows fuel economies of the three conditions and improvement rates based on the normal driving condition. Figure 5 illustrates average fuel economies where an error bar represents a standard deviation. For all subjects, average fuel economy of FC-meter condition is compared with that of Normal driving condition in the left part of Fig. 5. For Subjects #1 – #6, that of J-Eco drive condition is compared with that of Normal driving condition in the center part of Fig. 5, and that of G-Eco drive condition for Subjects #7 – #12 is also compared with that of Normal driving condition in the right part of Fig. 5.

Table 1 Fuel economy [km/l]

| Sub. | Normal driving | FC-meter | Eco-Driving |
|---|---|---|---|
| #1 | 9.95 | 9.23 (-7.2%) | 10.74 (+7.9%) |
| #2 | 10.07 | 11.69 (+16.1%) | 12.05 (+19.7%) |
| #3 | 11.00 | 12.43 (+13.0%) | 12.18 (+10.8%) |
| #4 | 8.86 | 10.42 (+17.6%) | 10.62 (+19.9%) |
| #5 | 10.23 | 11.22 (+9.6%) | 12.16 (+18.8%) |
| #6 | 8.86 | 9.33 (+5.4%) | 10.31 (+16.4%) |
| #7 | 9.20 | 10.01 (+8.8%) | 11.56 (+25.7%) |
| #8 | 8.36 | 9.60 (+14.9%) | 10.00 (+19.7%) |
| #9 | 7.58 | 11.00 (+45.2%) | 10.50 (+38.5%) |
| #10 | 11.14 | 10.51 (-5.7%) | 9.81 (-11.9%) |
| #11 | 10.62 | 12.41 (+16.9%) | 11.69 (+10.1%) |
| #12 | 9.18 | 8.60 (-6.3%) | 10.63 (+15.8%) |

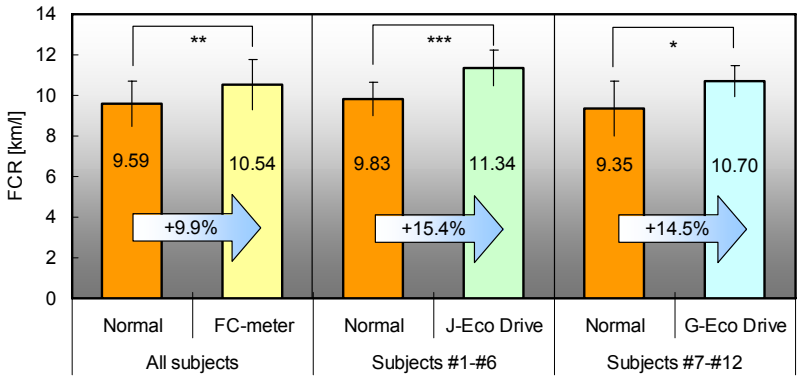



Fig.5 Average fuel economy

### 5.1.1. Effects of fuel consumption meter

First, let us discuss the experimental result of FC-meter condition. The fuel economy was increased by 9.9% ($p < .05$), although the subjects did not receive any instructions to improve the fuel economy before the experiment. The improvement rate is a little bit smaller than that of the eco-driving conditions discussed below. However, fuel economies of subjects except #1, #10, and #12 are comparable to those of the eco-driving conditions.

### 5.1.2. Effects of eco-driving instructions

As shown in Fig. 5, the fuel economies were increased by 15.4% in the case of J-Eco drive condition, and 14.5% in the case of G-Eco drive condition. The experimental results denote the obvious effectiveness of the eco-driving instructions quantitatively. However, in the experimental results, there is no significant difference in the improvement rate between the Japanese eco-driving and the German eco-driving.

## 5.2. Driving Behavior

### 5.2.1. Driving Behavior of Fuel Consumption Meter Group

This manuscript defines '*coasting state*' by the state where both the gas pedal input and the brake pedal input are zero and the acceleration of the vehicle is negative. Table 2 shows the ratio of coasting to total travel time of each subject, and Fig. 6 describes the average ratio of coasting. As shown in Fig. 6, the ratio of coasting of FC-meter condition is larger than that of Normal driving condition. The growth rate (+55.1%) is much larger than that in the case of J-Eco drive condition (+13.6%). The subjects can confirm that the instantaneous fuel economy figure on the fuel consumption meter increases rapidly when the driver releases the gas pedal. That is, they can learn how to improve the fuel economy by themselves through the real-time feedback of their driving behavior. After the experiment, all subjects answered that they had wanted to improve the fuel economy figure presented on the fuel consumption meter. Consequently, the experimental results imply that only the presentation of the fuel consumption meter will cause an intrinsic motivation to improve the fuel economy.

### 5.2.2. Driving Behavior of Eco-Driving Group

The major difference of the two eco-driving instructions is acceleration; gentle acceleration in the Japanese eco-driving and slightly faster acceleration in the German eco-driving. Therefore, the following indices about driving behavior were investigated to clarify the difference of the both eco-driving behaviors; 1) ratio of coasting (Fig. 6), 2) a relationship between the velocity and the acceleration (Fig. 7), and 3) a relationship between the velocity and the headway distance (Fig. 8). The analysis revealed that the Japanese eco-driving instructions provoked gentle acceleration and lengthened the headway distance while the German eco-driving instructions had no influence on acceleration and headway distance. It implies that the Japanese eco-driving instructions will cause traffic congestion. As for the ratio of coasting,

Table 2　Ratio of coasting to total travel time [%]

| Sub. | Normal driving | FC-meter | Eco-Driving |
|---|---|---|---|
| #1 | 17.20 | 13.68 (-20.5%) | 16.37 (-4.8%) |
| #2 | 9.85 | 18.74 (+90.3%) | 14.22 (+44.4%) |
| #3 | 13.34 | 21.25 (+59.3%) | 9.55 (-28.4%) |
| #4 | 9.45 | 15.70 (+66.1%) | 12.55 (+32.8%) |
| #5 | 11.49 | 18.70 (+62.8%) | 16.21 (+41.1%) |
| #6 | 13.52 | 18.90 (+39.8%) | 16.11 (+19.2%) |
| #7 | 9.27 | 21.87 (+135.9%) | 22.62 (+144.0%) |
| #8 | 8.07 | 14.74 (+82.7%) | 17.22 (+113.4%) |
| #9 | 6.68 | 18.72 (+180.2%) | 20.95 (+213.6%) |
| #10 | 8.50 | 7.12 (-16.2%) | 15.06 (-77.2%) |
| #11 | 11.80 | 14.33 (+21.4%) | 21.52 (+82.4%) |
| #12 | 10.17 | 16.87 (+65.9%) | 22.68 (+123.0%) |

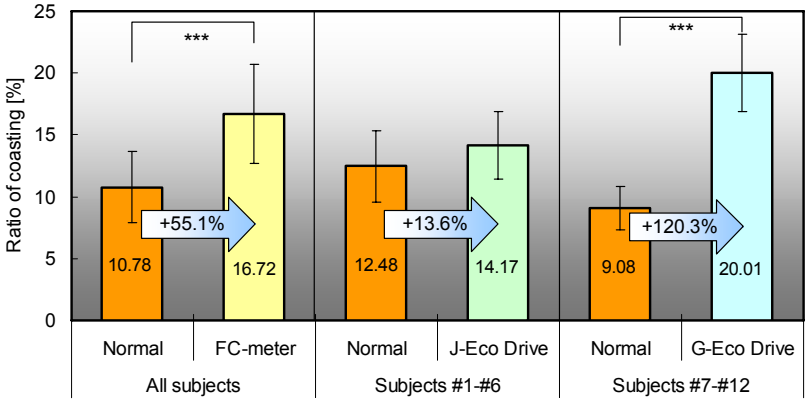
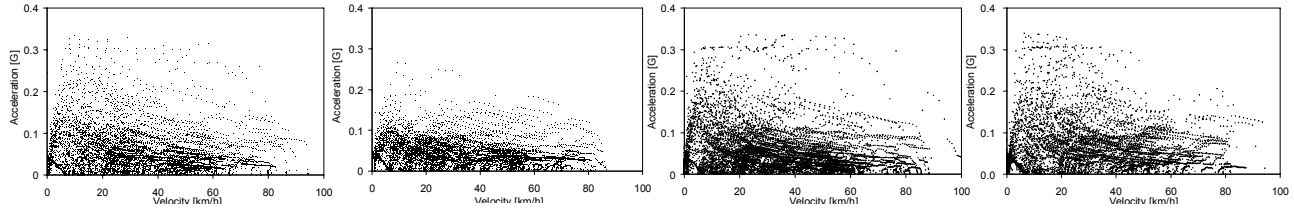
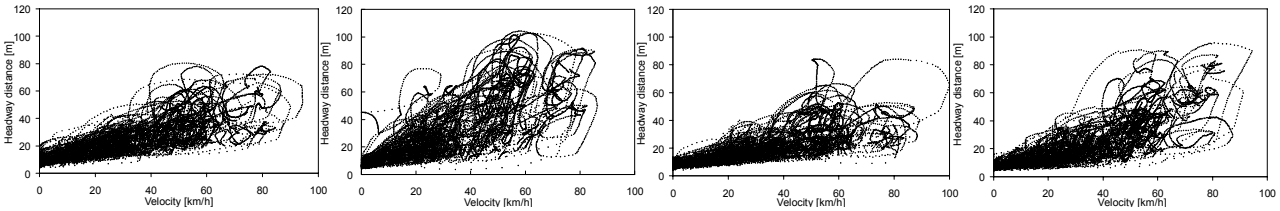



Fig.6 Average ratio of coasting




(a) Normal driving (Subs. #1- #6)　(b) J- Eco Drive (Subs. #1- #6)　(c) Normal driving (Subs. #7- #12)　(d) G-Eco Drive (Subs. #7- #12)

Fig.7 Distribution graph relating velocity [km/h] to acceleration [G]




(a) Normal driving (Subs. #1- #6)　(b) J- Eco Drive (Subs. #1- #6)　(c) Normal driving (Subs. #7- #12)　(d) G-Eco Drive (Subs. #7- #12)

Fig.8 Distribution graph relating velocity [km/h] to headway distance [m]

that in the case of the German eco-driving was markedly increased. It is the greatest characteristic of the driving behavior in G-Eco drive condition.

After the eco-driving experiment, the subjects were asked if it was easy to perform the eco-driving. One subject in J-Eco drive condition and two subjects in the case of G-Eco drive condition answered that the eco-driving was difficult. In other words, some subjects felt negative about the eco-driving behavior derived from the external instructions. The results suggest that the negative factor would prevent the value of the eco-driving from being internalized, and then, the behavior may not be continued in the long term.

## 6. CONCLUSIONS

In order to evaluate the effectiveness of the eco-driving instructions and the presentation of the fuel consumption meter on the fuel economy, this study performed three types of the driving simulator experiments under the same following situation; 1) the normal driving, 2) the driving when the fuel consumption meter was presented, and 3) the driving after the instructions for Japanese or German eco-driving.

In the case of FC-meter condition, the fuel economy was improved by approximately 10%, and furthermore, all subjects answered that they had wanted to improve the fuel economy figure presented on the fuel consumption meter. Accordingly, the results suggested that the presentation of the fuel consumption meter would cause an intrinsic motivation.

The eco-driving instructions improved the fuel economy by approximately 15%. The detailed analysis of driving behavior revealed that the subjects who had received the Japanese eco-driving instructions tended to expand the headway distance because the instructions recommended gentle acceleration, while the German eco-driving instructions had an insignificant influence on the following behavior. Therefore, in the future, we will perform a traffic simulation which includes a following model of the Japanese eco-driving in order to verify the traffic congestion problem.

## REFERENCES

[1] JAMA (Japan Automobile Manufacturers Association, Inc.): Reducing CO2 Emissions in the Global Road Transport Sector, PDF (2008)

[2] Ford-Werke GmbH: Ford Eco-Driving, http://www.ford-eco-driving.de/

[3] S. Matsumoto, I. Kobayashi, A. Nakamura, H. Kawashima: Economic evaluation of influence on traffic flow by eco-driving, Annual report of JSTE, Japan Society of Transportation Economics, pp.169-178 (2006) [in Japanese]

[4] H. Kato, S. Kobayashi: Factors Contributing to Improved Fuel Economy in Eco-Drive, Journal of JSAE, Vol. 62, No. 11, pp. 79-84 (2008) [in Japanese]

[5] R. M. Ryan, E. L. Deci: Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being, American Psychologist, Vol. 55, No.1, 68-78. (2000)