How does driving behavior change when following an eco-driving car?

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Abstract

To realize the sustainable transportation system in Japan, the issue to reduce CO\textsubscript{2} emission made by the automobiles has become very serious. Among the countermeasures discussed and proposed, the eco-driving has been treated as very important and believed to be very effective. The eco-driving means changing the driving styles to be much more economically and ecologically. This does not only apply to the cars doing the eco-driving but also affect the cars following the eco-driving cars. Furthermore, by considering most of the studies up to now had been based on the computer simulations and there had been only a few studies that were based on the real situation, we conducted a test run by using vehicles on the public roads under the normal traffic conditions. This paper is to report a part of the results of our test run. The driving data were recorded by the on board unit FCM-GPS·MMC produced by TECHTOM being used together with EC15WWF-40. The driving behaviors of the followed cars were recorded by the video camera taken from the back window of the last car of the eco-driving vehicle queue. The analysis mainly on that how many cars kept in following and how many cars gave up the following and then overtook the eco-driving car. As a result, we found that whether the following cars change their behaviors also depends on how perfect the followed car does the eco-driving. Here, the eco-driving is described by three indicators: tenderly starting, less change of speed and early accelerator off. Moreover, whether the eco-driving car has a sticker or not affected the behavior of the following cars, too.

Keywords: Eco-driving; car-following behavior; social experiment; video camera application; on board unit records

1. Introduction

In Japan, the CO\textsubscript{2} emissions from automobiles shared 87.3\% (Foundation for Promoting Personal Mobility and Ecological Transportation) of that in the transportation section in the 2007 fiscal year (from April 2007 to March 2008), so that it is very important task to reduce the CO\textsubscript{2} emissions from automobiles. In order to reduce CO\textsubscript{2} emission of automobiles, promotion of eco-driving is considered being effective. The eco-driving means to change driving styles to be more economically and ecologically. Regarding the effects of the eco-driving, Kobayashi et al. analyzed the influences on the traffic flows by a micro-simulation and concluded the eco-driving to be...
effective to reduce the fuel consumption and CO₂ emission. On the effectiveness in reducing CO₂ emission by eco-driving in real world, Kato & Kobayashi and Taniguchi reported that the eco-driving reduced 10%-20% of fuel consumption in Japan which is proportionally to CO₂ emission. In Europe Beusen et al. reported the fuel consumption was a reduction of 5.8% although there were large differences between individuals. What kinds of driving are eco-driving? To answer this question, Ericsson (2001) gave a detail analysis on which pattern factors were main factors influencing on fuel-use and exhaust emission on the basis of a classification on the driving patterns (Ericsson, 2000). As a result, 62 driving patterns parameters were calculated for each of 19230 driving patterns collected in real traffic and finally were reduced to 16 independent driving patterns factors by using factorial analysis. To evaluate the driving and promote the eco-driving through providing the information to the drivers, some systems have been developed and put into the applications in Japan (e.g. Techtom, NEC soft, Ltd. and Ando et al. (2010). By applying these systems, Kato & Kobayashi, Mori & Makishita, and Ando et al. (2011) discussed on the basis of the test run in Japan. In Europe CIECA implemented an internal project and summarized the experiences in “expert” countries: Finland, Netherlands, Germany, Switzerland and Sweden. All of these studies allow us understanding the effects of the eco-driving quite clearly. Furthermore, Zarkadoula et al. reported the effect for the bus drivers. However, the eco-driving promotion does not only apply to the cars doing the eco-driving but also affect the cars following the eco-driving cars. When a driver drives a car in a crowded traffic flow or in a car queue, the other cars may be affected by the behavior of the eco-driving car. Totally, the fuel consumption may become worse. Regarding this kind of influences on the cars following the eco-driving cars, there are not enough researches / studies although Kato et al. (2009) made an analysis by using the micro-simulation and gave us some interesting results. Furthermore, there have been few studies being based on the real traffic situation. In order to know what will happen when an eco-driving cars queue appears in the streets, we conducted a test run by using 15 vehicles on the public roads under the normal traffic conditions, in other words, there was no traffic regulations for test run. As a limitation, the drivers of the eco-driving cars were not allowed to change their order by passing a vehicle ahead his vehicle.

In this study, we focused on the drive behaviors of the followed cars and recorded those behaviors by the video camera taken from the back window of the last car of the 15 eco-driving vehicles queue. The analysis mainly on that how many cars kept in following and how many cars gave up the following and passed the eco-driving car through. This paper is to report the analysis based on the data collected during the test run.

2. Assumption on Car-Following Behaviors and Basic Definitions

When a car is controlled in the eco-driving mode, if we assume the following car is influenced by the eco-driving car, both cars will behave quite similarly. That is, both cars are kept driving in a nearly fixed time-distance. This state can be defined as the car following state. In viewpoint of the traffic engineering, there are many different definitions (e.g. Handbook of Traffic Engineering defines the car following state in the expressways by two indicators: one is that the difference of the speeds of two cars is not less than 5km/h and not larger than 10km/h; another is that the head time-distance is between 3 to 4 seconds.) on this car following state. The traffic flow theory, such as provability model, hydromechanics model and following car model, are proposed. However those theories are usually too complicated to collect and analyze the data. Thus, we simply define this car following state here as that the car following is the state where the time-distance between two cars is less but nearly equal to 3 seconds. Assuming the speeds of the cars are 20km/h, the distance is about 17m, and if that are 30km/h then the distance is about 25m.

Table 1 lists the considerable behaviors or actions when the car following state is over. All behaviors / actions listed here except the overtake are what are difficult to be avoided or necessary in order to get to the destination. As the overtake is not necessary action to get to the destination, we may think to reduce the overtakes so that let the objective eco-driving car affects the following car as long as possible and make the eco-driving effect spread to the following cars.
3. Description of Social Experiment

Table 1. Drive behaviors / actions when the car following state is over

<table>
<thead>
<tr>
<th>Behavior &amp; Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtake</td>
<td>The following car overtakes eco-driving car.</td>
</tr>
<tr>
<td>Break</td>
<td>The third car breaks into queue between eco-driving car and following car</td>
</tr>
<tr>
<td>Stopped by signal</td>
<td>The following car stops at a signalized crossing because of red signal after eco-driving car passed through crossing</td>
</tr>
<tr>
<td>Following car changed lane</td>
<td>The following car changed lane</td>
</tr>
<tr>
<td></td>
<td>(Changed lane to turn at crossing without overtaking)</td>
</tr>
<tr>
<td>Eco-driving car changed lane</td>
<td>The eco-driving car changed the lane</td>
</tr>
<tr>
<td>Turn left</td>
<td>The following car turns left</td>
</tr>
<tr>
<td>Turn right</td>
<td>The following car turns right</td>
</tr>
</tbody>
</table>

3.1. Outline of the social experiment

The social experiment, or called test run, was conducted on October 22 (Thu.) and 23 (Fri.), 2009. The fields are three road sections of the National Highway 248 located in Toyota City. The total road length is 6.4 kilometers. In order to make the analysis under the different road traffic conditions, the test run was carried out by using 15 same model vehicles from morning through evening. Totally, 16 round trips in two days were conducted. One hour rest after every two round trips was taken.

Regarding the test runs, we asked all drivers of the eco-driving cars to drive as we requested for each round trip after one normal driving round trip. Here, the normal driving is the driving without directions to do eco-driving. The contents of the eco-driving are the following three styles: tenderly starting (sometimes called e-start in Japan), less change of speed and early accelerating off. All eco-driving cars were requested to run on the first lane (the left lane) in principle. All eco-driving cars were putted by a sticker shown in Fig. 1 where a notice, that this car is implementing the eco-driving, is written.

![Eco-driving car with a sticker and the sticker putted on the eco-driving cars](image)

3.2. Outline of the road sections to make the test runs

The Highway No. 248 is a major road located in Toyota City as shown in Figure 2. The road consists of the sections in the urban area and the suburban area. Therefore there are different land use regulations. Here three sections are defined according to the characteristics of each road section. The representative characteristics are summarized in Table 2. The traffic flows of these three road sections are 27,200–31,700 vehicles/day in terms of the Road Traffic Survey in 2005.

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1 Overtake is defined on the two-lane road here so it includes the case that the overtaking car isn’t back to the original lane but doesn’t include the case that the overtaking car wasn’t running at the same lane before overtaking.
Fig. 2 Route map of the test run
### Table 2 Outline of the three road sections

<table>
<thead>
<tr>
<th></th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>2.1 km</td>
<td>1.1 km</td>
<td>3.2 km</td>
</tr>
<tr>
<td>No. of lanes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South direction</td>
<td>1</td>
<td>South direction: 2</td>
<td>South direction: 2</td>
</tr>
<tr>
<td>North direction</td>
<td>2</td>
<td>North direction: 2</td>
<td>North direction: 2</td>
</tr>
<tr>
<td>Density of signals</td>
<td>4.3 per km</td>
<td>1.8 per km</td>
<td>3.1 per km</td>
</tr>
<tr>
<td>Speed limitation</td>
<td>50 km/h</td>
<td>50 km/h</td>
<td>60 km/h</td>
</tr>
<tr>
<td>Slope</td>
<td>South direction: +0.6%</td>
<td>South direction: +1.0%</td>
<td>South direction: -0.5%</td>
</tr>
</tbody>
</table>

#### 3.3. Data collection

In order to collect the travel speeds et al. from the engine computer and the date, the time and the positions by the GPS equipment. The drive data were recorded every one second by the on board unit FCM-GPS·MMC produced by TECH TOM being used together with EC15WWF-40. By the way, this equipment had been improved from the market model to be able to memory the data by a SD card. Furthermore, the behavior & action of the following car was observed and recorded by a video camera set on the back seats of the last car at the eco-driving cars queue. Moreover, in order to discuss the relationship between the traffic flows and the behaviors/actions of the following cars, the traffic counts were made in the three road sections respectively, too.

### 4. Observed Results of Car Following Behaviors

One round trip implies running 6 road sections, so 16 round trips let us be able to observe on 96 road sections totally. As a result, about 592 minutes observations were undertaken. The observations include the number and time of car following, the behaviors when the car following is over, the place/position/point where the car following finished and so on.

The observations told us that the number of car following actions is 205, and total car following time is 448.8 minutes. The car following time shared 75.8% of the total driving time as given in Fig. 3. It is clear that the effect of an eco-driving car is not limited itself but spreads for the following cars definitely.

The behavior/action when the car following is over is summarized in Fig. 4. That the percentage of cars turning left is the largest may be because the eco-driving car was requested to keep running in the first lane in principle. The number of cars to overtake shares 21%.

Furthermore, as given in Fig. 5, comparing to the average car following time, which is 2.2 minutes, the car following time of the cars finally overtaking the eco-driving cars is relatively shorter. It is only 1.5 minutes. This means that the control of the overtaking may increase the car following time and enlarge the effect of the eco-driving cars.

Moreover, Fig. 6 shows the relationship between the traffic flows and the percentages of making the car following over the total running time. Here there may be some bias with the traffic flows because they were counted at only one point respective with one road section. We can know that the percentages increase along with the traffic flows increase.

![Figure 3 Percentage of following time](image-url)
Figure 4 Drive behaviors when the car finished following

Figure 5 Average following time by the drive behaviors when the car finished following

Figure 6 Traffic flows and percentages of car following time over total running time
On the other hand, as shown in Fig.7, it is difficult to conclude on the relationship between the travel speeds and the percentages of making the car following over the total running time. Although the percentages of making the car following movements showed some differences when the travel speeds differed. We can not see a clear tendency definitely. In another word, we may say there is no clear relationship between the travel speeds and the percentages of making the car following over the total running time.

5. Analysis on Relationship between Overtaking and Eco-driving

If an eco-driving car makes the following cars tend to overtake, the eco-driving effect on the following cars will be deducted. This means that the relationship between the overtaking and the eco-driving is an important issue. In this study, we tried to make an analysis on it.

The data that we used are obtained from the above social experiment, too. However, the data collected on the road sections with single lane in one direction have been eliminated because the overtaking is basically impossible there. As a result, 178 car following actions have been selected. The followings focus on the relationship between the overtaking and the eco-driving. Here the eco-driving means what we requested: the tenderly starts, the less change of speeds and the early accelerating off. Furthermore, a discussion on the eco-driving cars with or without stickers is made additionally. Regarding the indicators to evaluate the eco-driving, the three actions that we requested are evaluated as the following method respectively.

- **Tenderly start**: because a tenderly start is defined as the start to spend more than 5 seconds to accelerate the speed to 20 km/h, we can judge the start with the speed lower 20 km/h when 5 seconds passed to be the “tenderly start”. Then the evaluation indicator is defined as the percentage of the “tenderly start” over all starts.
- **Less change of speed**: the “less change of speed” driving means the driving style at a stable speed and with less accelerations and decelerations. This can be explained as that the variation of the speeds is small. Therefore, the standard deviation of the speed is used as the evaluation indicator here.
- **Early accelerating off**: the early accelerating off is to make use of the engine brake actively so as to reduce the fuel consumption. We consider that this driving style being realized better means the percentage of the inertial movement time over all accelerating off time (see Figure 8) is greater. Thus this percentage is defined as the indicator of the early accelerating off. However, by considering that the movement time because of the creep and the braking time in cases of the traffic congestion or stopping is quite different with the normal driving, this influence should be eliminated. In our analysis, we define the moving at the speeds under 5 km/h as the creep movement in terms of the study made by JAF (2003), and then eliminate the data of the creep movement for the evaluation of the early accelerating-off.
The relationships among the number of car following behaviors/actions, the percentage of overtaking and the three eco-driving styles that we requested the drivers to do are given in Fig. 9 to Fig.11 respectively. The horizontal directions are the indicators of the eco-driving. The left vertical axis is the number of the observed car following actions. The right vertical axis is the percentage of the overtaking. Generally, there are some biases because we divided the values of the eco-driving indicators at equal intervals and the samples with respective to each interval are quite different. However, at least, the percentages of the overtaking do not increase along with the change of the eco-driving indicators. That means, the eco-driving does not bring the increase of the overtaking.

The relationships among the number of the car following behaviors, the percentage of the overtaking and with or without a sticker put on the car are shown in Fig.12. Although the result of a chi-test analysis hasn’t shown a significant difference between “with” and “without” stickers, the percentage of the overtaking with the stickers is greater than that without the stickers. This result tells us that the eco-driving cars with the “do eco-driving” stickers may cause the following cars to overtake more frequently.
Figure 10 Relationships among number of car following behaviors, percentages of overtaking and less change of speeds

Figure 11 Relationships among number of car following behaviors, percentages of overtaking and early accelerating off

Figure 12 Relationships among number of car following behaviors, percentages of overtaking and with/without sticker
6. Summary and Conclusions

This paper reported about the eco-driving and its influences on the basis of the social experiment by using 15 vehicles to make a queue and do eco-driving on the public roads. The purposes of this social experiment are appealing the eco-driving and promoting it, evaluating the eco-driving quantitatively, observing and taking consideration of the influence to the other vehicles, and analyzing the eco-driving effects comprehensively. Among the above purposes, in this paper, we focused on the behaviors of the following cars and made some points become clear.

1. The percentage of car following time over all running time is about 76%. That is, on the urban roads, during more than three fourth of the running time, the behaviors of the cars are influenced by the followed car. In another word, the eco-driving car may affect the following cars to drive economically and ecologically even the drivers may not be active.

2. The average car following time is 2.2 minutes. However, the car following time of the overtaking cars is 1.5 minutes. Because the followed cars are doing eco-driving, we can say that as long the car following time is, as economically and ecologically the following cars are. Therefore, to realize the aim of promoting the eco-driving, one effective approach is to reduce the number of the overtaking cars. It has the same meaning of increasing the car following time.

3. On the other hand, in general there is no direct relationship statistically between the implementation of the eco-driving made by the followed cars and the overtaking action of the following cars.

4. However, if the sticker with the message “do eco-driving” is put on the eco-driving car, number of the overtaking behaved by the following cars may increase. Therefore, we should forget the promotion effect of the stickers and call the people to do the eco-driving in the other ways instead of sticking on the eco-driving cars directly. As a result, it is more effective to approach the largest total outcomes because more following cars may do the eco-driving passively.

Finally, being the further study topic, the relations among the traffic flows on each lane and the eco-driving behaviors should be analyzed in terms of a much more detail traffic flows survey.

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