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Notes and comments

Using on-board logging devices to study the longer-term impact of an eco-driving course

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ABSTRACT

In this paper the long-term impact of an eco-driving training course is evaluated by monitoring driving behavior and fuel consumption for several months before and after the course. Cars were equipped with an on-board logging device that records the position and speed of the vehicle using GPS tracking as well as real time as electronic engine data extracted from the controller area network. The data includes mileage, number of revolutions per minute, position of the accelerator pedal, and instantaneous fuel consumption. It was gathered over a period of 10 months for 10 drivers during real-life conditions thus enabling an individual drive style analysis. The average fuel consumption four months after the course fell by 5.8%. Most drivers showed an immediate improvement in fuel consumption that was stable over time, but some tended to fall back into their original driving habits.

1. Introduction

Road transport CO_2 emissions form an important component of greenhouse gas generated in most developed countries and are projected to rise in the future. Among the policy options to reduce these emissions is eco-driving. Reducing fuel consumption significantly by teaching drivers how to change their driving behavior is potentially a very cost-efficient way to reduce energy use and emissions (International Energy Agency, 2005).

Numerous studies have looked at the short-term impact of eco-driving on fuel consumption. European Conference of Ministers of Transport/International Energy Agency (2005) found an average estimated 5% reduction for OECD (Organisation for Economic Cooperation and Development) regions based on an expert analysis of available literature. Few studies report on the long-term impacts of fuel-efficient driving courses. Wahlberg (2007) monitored fuel consumption reduction in busses and recorded 2% fuel savings during the 12 months after training. Zarkadoula et al. (2007) mention fuel savings on busses of 4.35% during a post training monitoring period of two months. Both studies report, however, that after a time drivers partially slip back to less environmentally friendly driving habits resulting in lower fuel savings than originally attributed to the courses.

Here we look at a long-term passenger car monitoring campaign that recorded driving patterns and fuel consumption from people participating in an eco-driving course. A panel of drivers was followed for up to 10 months to analyze the impact on fuel consumption and on different driving parameters.

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Table 1
Details on the vehicles used in the eco-driving experiment.

Id	Car model	Fuel type	Year	Monitoring start	Eco-driving course	Monitoring stop
1	Citroen Xsara	Diesel	2002	December/2007	March/2008	June/2008
2	Citroen C5	Diesel	2003	August/2007	December/2007	April/2008
3	Renault Clio III 1.2 16V	Gasoline	2005	March/2008	July/2008	November/2008
4	Lexus IS 220 d	Diesel	2006	February/2008	June/2008	October/2008
5	Renault Vel Satis 2.2 cdi	Diesel	2003	February/2008	June/2008	November/2008
6	VW golf	Diesel	2000	October/2007	December/2007	April/2008
7	Audi A3	Diesel	2007	February/2008	June/2008	November/2008
8	Peugeot 206 1.4 Hdi	Diesel	2002	November/2007	March/2008	July/2008
9	Ford mondeo 2.0 tdc	Diesel	2002	December/2007	March/2008	June/2008
10	Audi A4 2.5d automatic	Diesel	2005	December/2007	March/2008	June/2008

2. Methodology

A data-logging device is used to monitor people's driving behavior accurately. In this section we will first describe this data collection device and then discuss the set-up of the panel survey and the eco-driving course.

2.1. On-board data collection device

Tracking the amount of fuel bought by participants over a long period of time introduces unwanted effects into an eco-driving experiment. The burden on the participants to record the details of every fuel purchase is high resulting in drop-outs. Secondly, bias may be introduced by directly confronting participants with their fuel use long before the eco-driving course. To obtain data in a long-term driving monitoring experiment without burdening its participants or introducing bias, we use an on-board device to monitor and log key driving parameters. The device is equipped with a memory card, a GPRS-modem, a GPS tracking system and is connected to the controller area network (CAN) of the vehicle. This allows monitoring and logging of two types of data: the position and speed of the vehicle by means of the GPS tracking system and electronic engine data extracted from the CAN-bus, which includes data on mileage, number of revolutions per minute (RPM), position of the accelerator pedal, gear selection, instantaneous fuel consumption and engine coolant temperature. The logging device is small (approximately 10 cm $\times$ 10 cm) and installed out of sight of the driver. Based on the decoding of the CAN messages, the device was programmed to log the required CAN parameters for a particular car. The logging device did not interfere with the engine management system. Data were read from the CAN, stored on the internal memory card of the on-board logger, and transmitted to a central server via the GPRS-modem on a daily basis.

Drivers could consult their recorded positions on a website, but not the data on their driving behavior was or fuel consumption. No information on their driving behavior was fed back to the drivers during the project so as not to influence their driving behavior. Drivers were requested to add additional information on a trip-by-trip basis concerning travel motives, the number of passengers and the actual driver of the vehicle. This last feature is important in this study as mostly multiple drivers could use the same vehicle and the actual driver for a particular trip was not always the same person that participated in the eco-driving course. Based on the trip declarations of actual drivers this effect was filtered out.

2.2. Experimental design

Participants in the experiment were solicited internally at VITO and externally using an announcement in a car magazine (*Autogids*). To be eligible, the candidates had to be the owner of the vehicle, the vehicle had to be of a model year later than 2001 (older vehicles generally do not have a CAN-bus) and had to be at least 2 years old at the start of the experiment because of warranty issues. Thirty vehicles were equipped with the on-board logging device, registered in Belgium, and predominantly used in the northern or Flemish speaking part of the country.

The information available on the CAN-bus can differ by manufacturer and model. As information on data protocols is not publicly available, signals had to be analyzed using a case by case testing approach to find out how different parameters are transmitted. Not all parameters were available for all cars because they were not found within the data stream or were simply not present on the CAN. Fuel consumption was registered for 20 vehicles. Throttle and RPM were registered for 20 and 21 vehicles. Further, for some cars an insufficient amount of data was logged, or not enough trips were explained by the driver.[1] Three drivers did not take the driving course. Thus, of the 30 cars equipped with the monitoring device, only 10 could be used for analysis (Table 1). This sample size is too small to learn lessons on the general impact of eco-driving but is large enough to indicate significant differences between individual drivers and their response over time to an eco-driving course.

About halfway through the project, participants were given a four-hour course on fuel-efficient driving (Table 1 gives dates). This course consisted of a drive with a test vehicle prior to the course, a session on the rules of fuel-efficient driving

[1] For 2 months before and after the course at least 100 km per month had to have been done by the driver.

and a second drive with the same vehicle but with guidance of an instructor. The main rules of fuel-efficient driving (or e-positive driving (www.e-positief.be) as it was called), can be summarized as:

1. Shift up as soon as possible (shift up between 2000 and 2500 revolutions/min).
2. At steady speeds use the highest gear possible and drive with low engine RPM.
3. Try to maintain a steady speed by anticipating traffic flow.
4. Decelerate smoothly by releasing the accelerator in time while leaving the car in gear (this is called "coasting").

Further, some additional driving style instructions were provided at the course:

5. Shut down the engine for longer stops, e.g. before a level crossing or when you pick somebody up.
6. Do not drive faster than 120 km h^{-1} (which is the legal speed limit on motorways in Belgium).

Vehicle data were logged to study the impact of this training course on fuel consumption and to check how well the different rules stated above were observed by the participants.

Over ten months 2.026 h of data, covering 116.355 km of travel, were collected, from the vehicles. Based on these 10 driving parameters were calculated. The selection of these parameters was based on their perceived relevance for eco-driving. Table 2 presents an overview of the selected parameters, their units and the corresponding abbreviations. Two trip related parameters, distance and the average speed, were also analysed to evaluate whether the travel pattern had changed significantly over time. All the parameters were calculated on a weekly basis.

3. Results

3.1. General effect of the eco-driving course

To get an overall picture of the effect of the course we performed a three-way ANOVA; the factors being the driver (1–10), the course (before or after the course) and the week. Table 3 shows the p-values of the effects and interactions of the factors for the different parameters. From this analysis of the dataset as a whole, we conclude that:

– Neither week nor course have a significant effect on weekly distance or average speed suggesting drivers did not change their travel patterns. Differences can therefore be attributed primarily to changes in driving patterns.
– The course has a significant effect on most driving parameters, except for average shifting point and time idling.
– The course has a significant effect on the fuel consumption of the population as a whole.
– The driver-course interaction has a significant effect on most behavioral parameters except for the time idling indicating that the size of the effect of the course depends on the driver.
– The week does not have a significant effect on fuel consumption. However the interaction driver-week has a significant effect that indicates that the change of the effect over time also depends on the driver.

Previous work by Vlassenroot et al. (2007) suggests that overall statistics for the population as a whole provide insufficient information to assess the impact of intelligent speed adaptation on driving behavior; the common aggregation problem. The

Table 2
Variables used.

Parameter	Unit	Abbreviation	Description	Rule
Distance	km	Tot_dist	Distance covered	
Average speed	km h^{-1}	Avg_speed	Average driving speed (time based)	
Average fuel consumption	l.100 km^{-1}	Avg_fc	Average fuel consumption	
Average shifting point	rpm	Avg_sp	Average engine speed reached before shifting to a higher gear during acceleration	1
Percentage distance coasting (3 s)	%	Dist_coast	% distance covered during prolonged coasting actions (prolonged coasting is defined as period of at least 3 seconds while fuel consumption = 0, and speed > 0)	4
Percentage time heavy acceleration	%	Time_acc	% time driven at accelerations > 1.5 m s^2	3
Percentage time heavy deceleration	%	Time_dec	% time driven at decelerations > 2.5 m s^2	3 and 4
Percentage time idling	%	Time_idl	% time standing still (v < 3 km h^{-1}) with the engine running (idling)	5
Percentage distance in optimal rpm	%	Time_rpm	% distance covered with engine speed between 1100 and 1700 rpm (optimal engine speed for steady speeds)	2 and 3
Percentage distance at more than 120 km h^{-1}	%	Dist_120	% distance covered at speeds higher than 120 km h^{-1}	6

Note: the relevance of each parameter to one or more eco-driving rules is indicated in the last column.

Table 3
Significance values of the effects and 2-factor interactions of a 3-way ANOVA.

Parameter	Course	Driver	Week	Course*driver	Course*week	Driver*week
Tot_dist		***			***	
Avg_speed		***			**	
Avg_fc	***	***				**
Avg_sp		***		***		**
Dist_coast	**	***		***	***	***
Time_acc	***	***	**	***	**	***
Time_dec	***	***		**		
Time_idl						
Time_rpm	***	***	*	***		**
Dist_120	***	***		***		*

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

fact that within this experiment the interactions of the course variable with the driver variable are very significant for most driving parameters, suggesting that the impact of the eco-driving course differs greatly between drivers.

3.2. Individual effects of the eco-driving course

Table 4 presents the results from a *t*-test on selected parameters to analyze the differences before and after the eco-driving course for each driver. The effects, values and confidence intervals of the effects are listed. The change in fuel consumption is expressed as a relative change (%) of the average fuel consumption (l/100 km) compared with the observation before the course.

It is seen that the trip parameters (average distance and average speed) did not change significantly between trips before and after the course, indicating that, on average, trips before the course were similar to those after it confirming the result of the three-way ANOVA.

The average fuel consumption across drivers decreased by approximately 6%; but there were variations between −12% and +3%. Fuel consumption decreased significantly after the course for seven drivers. The differences in fuel consumption are also reflected in a changing driving behavior. Parameters showing significant improvement for at least seven drivers are average shifting point, distance coasting and distance driven with low rpm. The shifting point decreased on average for all drivers with 97 rpm, with extreme values around 200–500 rpm. The percentage of distance coasting increased on average by 1.16% and the percentage of time driven at low rpm increased on average by 12.2%. Drivers number two and four who did not achieve fuel savings after the course, also show significant improvements in the time driven at low rpm. The average shifting point did not change significantly for them indicating the importance of this parameter in achieving fuel savings.

The percentage of time in heavy acceleration or deceleration decreases by 0.26% and 0.22%. These changes may seem small, but these events occur less frequently compared to coasting. The fact is that people did change their acceleration and deceleration behavior in most cases.

No significant impacts were observed in the time idling. In general, it decreases but the impact is significant in only two cases. The number of longer stops justifying engine shutdowns is probably very limited. The fact that idling decreases is also

Table 4
Impact of the eco-driving course on the selected parameters.

Parameter	Driver										
	Average	1	2	3	4	5	6	7	8	9	10
Tot_dist	−33	−3	−26	−31	−1	−34	−116**	+1	+30	−75	−75
Avg_speed	−0.7	−4.2	−0.9	+4.0	+0.0	+0.3	−1.7	+1.0	−1.5	+0.2	−4.3
Avg_fc (%)	−5.8	−10.3***	+3.0	−12.0***	+2.2	−11.8**	−4.6	−4.4*	−6.6***	−7.9***	−5.8*
Avg_sp	−97	−94***	−37	−125***	+16	−546***	−170***	−38*	−187***	−107***	+315
Dist_coast	1.16	+2.1***	+0.5	+2.4***	+1.9***	−2.1***	0.0	+1.5**	+2.7***	+1.1*	+1.5
Time_acc	−0.26	+0.0	−0.3	−0.2*	0.0	−0.6***	−0.4	−0.2	0.0	−0.4***	−0.5**
Time_dec	−0.22	+0.2**	−0.4*	−0.6***	−0.2*	−0.1	−0.2	−0.6***	0.0	−0.2**	−0.2**
Time_idl	−1.37	−0.6	+0.4	−3.6***	−0.8	−3.3	−1.7	−1,1	−0,7	−0.2	−2.0*
Time_rpm	12.2	+8.3**	+10.7***	+15.0***	+29.2***	+10.2***	+18.1**	+6.0*	+11.3***	+4.3	+8.9
Dist_120	−6.3	−14.1***	−2.1**	−2.4	+1.1	−34.9***	0.0	−3.8	−2.5	−1.9	−2.0

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

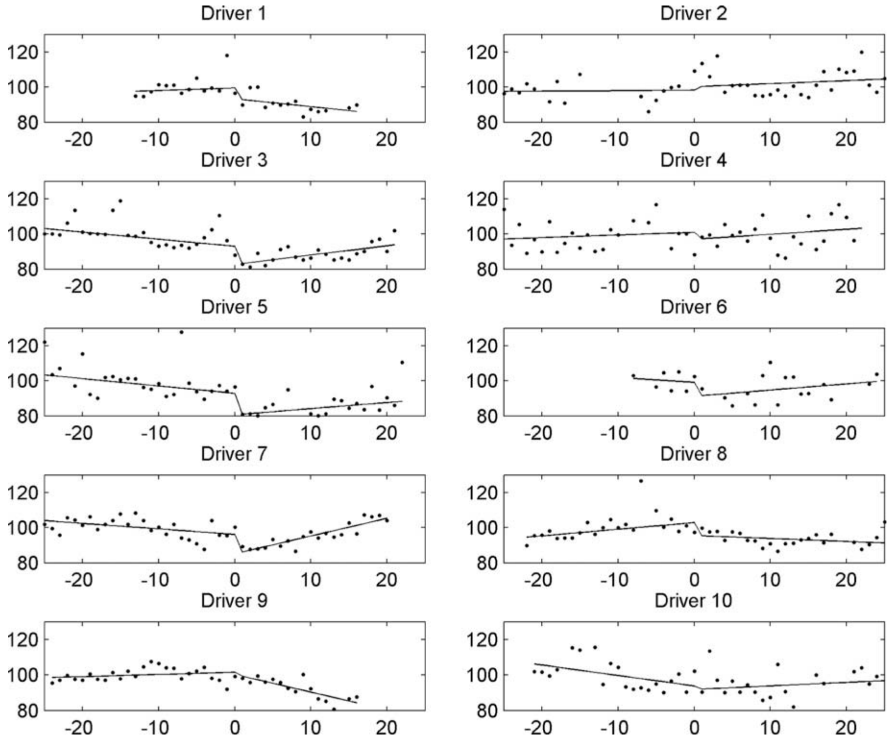

Fig. 1. Evolution of the weekly average fuel consumption (average consumption before course = 100, week course = 0).

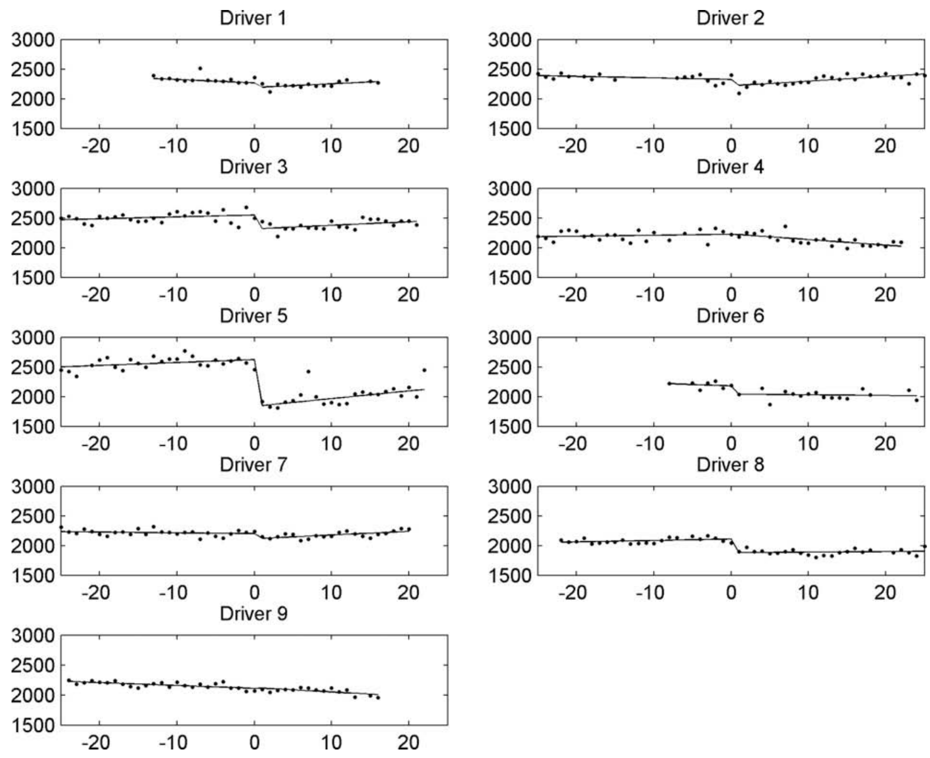

Fig. 2. Evolution of the weekly average shifting point in rpm (week course = 0, driver 10 is automatic).

Table 5
Changes in the driving parameters over time.

Factors	Before		After	
	Increase	Decrease	Increase	Decrease
Avg_fc	1	4	2	1
Avg_sp	0	2	5	3
Dist_coast	2	2	5	1
Time_acc	2	2	4	0
Time_dec	0	1	1	2
Time_idl	0	3	3	1
Time_rpm	1	1	5	1
Dist_120	1	1	0	0

Note: values indicate the number of drivers with a significant effect before or after the course.

not just due to increased shutdowns of engines during long stops; people showing increased coasting distance will also spent less time standing still at crossroads and traffic lights. The percentage of distance driven at speeds higher than 120 km h^{-1} decreases on average with 6.3%. This decrease was significant for only three drivers.

3.3. Individual effects over time

We analyzed the different parameters on a weekly basis to check for a possible learning or fading effect. Figs. 1 and 2 show the impact for the individual drivers over time for the parameters fuel consumption and shifting point. Regression lines were fitted before and after the course to indicate trends over time. Table 5 shows the number of drivers for which the slopes of these regression lines before and after the course significantly decreased or increased.

Some variables already displayed a change over time before the eco-driving course. Four drivers already realized a significant decrease in fuel consumption, indicating that these drivers already practiced more environmentally friendly driving behavior before participating. Evidence for a changed driving style can be found in the driving variables where we observe decreasing average shifting points. The average fuel consumption after the course gradually increases again for 20% of drivers, while for one driver fuel consumption keeps improving significantly after the course. For the other seven drivers, no significant change in fuel consumption is seen in the months after course.

The temporal variations in the parameters after the eco-driving course demonstrate that for some factors most drivers continue to improve their eco-driving skills. This is so for the percentage of distance covered by coasting and the percentage of distance covered in optimal gear. Other parameters, like heavy acceleration and idling tend to deteriorate again after the course – a gradual deterioration or increase for four drivers, no gradual improvement in heavy acceleration for any driver. The evolution of the average shifting point is very different between drivers. While shifting points tend to increase again for five drivers, three drivers manage to further reduce their average shifting points.

All this suggests that post-educational effects can vary strongly from one driver to another. While some drivers use what they have learned to continue improving their eco-friendly driving style, others tend to "forget", suggesting the latter may need more repetitive training.

4. Conclusions

This project has shown that on-board logging devices can be used to study driving behavior over relatively long-time periods. Collecting data through CAN messages provides large amounts of additional information on fuel consumption, engine speed, and gear shifting on a second by second basis.

The mean change in fuel consumption for all drivers in the study after their eco-driving course was a reduction of 5.8%, but with large differences between individuals. We may, though, have underestimated the potential effect of the eco-driving course because drivers participated on a voluntary basis and 40% of them had already reduced their fuel consumption gradually before attending the course. The differences in fuel consumption are also reflected in changes in driving behavior parameters based on the eco-driving tips: shifting point during acceleration moved closer to the optimal 2000 rpm, the distance driven while coasting increased, fewer heavy accelerations and decelerations events occurred, and the distance driven at steady speeds using the optimal gear increased. However, not all drivers realized significant improvements; 20% achieved no fuel savings.

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